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# BLAST CAPACITY EVALUATION OF GLASS WINDOWS AND ALUMINUM WINDOW FRAMES

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LARGE CALIBER
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of static and dynamic tests were performed to evaluate the blast-resistant capacity of tempered and regular glass windows and aluminum window frames used in buildings at Army Ammunition Plants. The test results indicate a maximum blast capacity of 30.3 kPa (4.4 psi) incident over-pressure from 900 kg (2,000 lb) of explosives for 6.35-mm (1/4-in) thick tempered glass panes mounted in rigid frames with a glass area of 1.86 sq m (20 sq ft) or less. For tempered glass mounted in aluminum window frames,

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the blast capacity was reduced due to frame distortions to 8.27 kPa (1.2 psi) for standard frames, and 17.9 kPa (2.6 psi) for strengthened frames. Design criteria developed based on the test results are presented and recommendations are made for testing of thinner glass windows.



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## SUMMARY

In many Army Ammunition Plants, non-operational, administration and other support buildings containing personnel are located at inhabited-building distance or greater from buildings containing explosives. In general, such buildings can withstand, or are designed to withstand, a blast overpressure of 8.3 kPa (1.2 psi) or less, with little or no damage except for window breakage. Moreover, operational buildings containing personnel can be located closer than inhabited-building distance which presents an additional hazard if windows are provided.

Glass breakage presents a severe hazard to personnel and has required that blast-resistant windows be specified in the design of buildings containing personnel, particularly where many people are involved. In order to evaluate the blast capacity of window glass and frames, a test program was undertaken by the Manufacturing Technology Division of the Large Caliber Weapons Systems Laboratory, U.S. Army Armament Research and Development Command (ARRADCOM).

Since window breakage with regular glass was known to have occurred at relatively low overpressure levels, i.e., less than 3.4 kPa (0.5 psi), it was of particular interest to evaluate the increased blast capacity offered by "safety" glazing materials under uniform loading. In addition, it was considered important to evaluate the effect that metal frames of the type used in modern office and industrial buildings may have on the capacity of such windows. The resulting test program consisted of static and dynamic tests of tempered and regular glass panes and aluminum frames. The results of the static tests were used as a basis for establishing pressure loadings and modifications of the window frames used in the dynamic tests.

Eleven static tests were conducted at ARRADCOM utilizing an hydraulic testing machine. The dynamic tests were performed at Dugway Proving Ground, Utah, under the direction of ARRADCOM and consisted of nine explosive tests utilizing 900 kg (2,000 lb) of explosives. Electronic gages were utilized to record the blast pressures for the dynamic tests. Still and motion picture coverage of the dynamic tests and still pictures of the static tests were provided for documentation purposes.

The static tests included tests on aluminum window frames, 6.35-mm (1/4-in) thick tempered and regular glass mounted in rigid wooden frames, and 6.35-mm (1/4-in) thick tempered glass mounted in standard and strengthened aluminum window frames.

The dynamic tests included tests on 6.35-mm (1/4-in) and 9.52-mm (3/8-in) thick tempered and regular glass mounted in rigid wooden frames, and 6.35-mm (1/4-in) thick tempered glass mounted in standard and strengthened aluminum window frames. The 9.52-mm (3/8-in) thick glass was included in these tests in case the 6.35-mm (1/4-in) thick glass did not have adequate capacity.

The test results indicate a maximum blast capacity of 30.3-kPa (4.4-psi) incident overpressure from 900 kg (2,000 lb) of explosives, for 6.35-mm (1/4-in) thick tempered glass mounted in rigid frames with a glass area of 1.86 sq m (20 sq ft) or less. For tempered glass mounted in aluminum window frames, the blast capacity was reduced, due to frame distortions, to 8.27 kPa (1.2 psi) for standard frames and 17.9 kPa (2.6 psi) for strengthened frames.

Thus, the window frame was found to be the critical element and it will be necessary in many cases to provide special frame designs to develop the blast capacity of the glass. The equivalent triangular load duration of the incident pressure for the dynamic tests was approximately 40 milliseconds. There was good correlation between the static and dynamic test results when the static failure loads were adjusted to equivalent blast pressures in accordance with calculated dynamic load factors.

The test results for the regular glass indicate a maximum blast capacity of 5.38-kPa (0.78-psi) incident overpressure for 6.35-mm (1/4-in) thick glass mounted in rigid frames with a glass area of 1.86 sq m (20 sq ft) or less. Regular glass was not tested in aluminum window frames.

There were no failures of the 9.52-mm (3/8-in) thick tempered glass when subjected to repeated overpressures up to 30.3 kPa (4.4 psi) at 40-msec equivalent triangular load duration. There was one failure of a 9.52-mm (3/8-in) regular glass pane when subjected to 10.8 kPa (1.56 psi) reflected pressure at a 20-msec equivalent triangular load duration.

Design criteria for maximum blast capacity versus blast load duration and glass type and thickness have been developed based on the test results. It is recommended that these criteria be utilized in the design of buildings at Army Ammunition Plants. Additional tests are recommended to evaluate the blast capacity of 3.18-mm (1/8-in) thick glass windows.

# INTRODUCTION

## Background

Window breakage represents a major hazard to personnel in administration and other support facilities at Army Ammunition Plants. In past incidents, glass breakage has been the major cause of injury even at buildings located at distances greater than inhabited-building distance from the explosion. Moreover, there may be requirements for windows in buildings located at less than inhabited-building distance. It was therefore necessary to investigate the blast capacity of strengthened glazing, including tempered safety glass and glass panes thicker than those used in conventional buildings.

Tempered glass consists of regular glass whose properties have been proportionally controlled and which has been rapidly cooled from near the softening point (annealed) to increase its mechanical and thermal endurance.

In order to obtain data related to the blast capacity of tempered glass windows compared to regular glass windows, a series of tests were undertaken by the Manufacturing Technology Division of the Large Caliber Weapons Systems Laboratory, ARRADCOM, as part of its overall Safety Engineering Support Program for the Project Manager for Production Base Modernization and Expansion. This report which was prepared with the assistance of Ammann & Whitney, Consulting Engineers, summarizes and evaluates the test results and presents recommended criteria for the design of blast-resistant windows.

## Purpose and Objectives

The overall purpose of the test program was to determine the increased blast-resistant capacity afforded by tempered glass windows compared to regular glass windows. The objectives of the test program are summarized below:

1. To evaluate the blast capacity of 6.35-mm (1/4-in) and 9.52-mm (3/8-in) thick tempered and regular glass panes.

2. To evaluate the effect of the strength and flexibility of aluminum window frames on the blast capacity of the windows.

## Format and Scope of Report

The following two sections describe the static and dynamic load tests, respectively, including the test procedures and results. These sections are followed by a section which compares and evaluates the static and dynamic test results and develops recommended design criteria. The last section presents the conclusions and recommendations. The appendix contains reproductions of the engineering drawings of the test structures and testing plans.

Since future standards of measurement in the United States will be based upon the SI Units (International System of Units) rather than the United States System now in use, all measurements presented in this report will conform to those of the SI System. However, for those persons not fully familiar with the SI Units, United States equivalent units of particular test data are presented in parentheses adjacent to the SI Units.

## STATIC LOAD TESTS

### General

Static load tests were performed on tempered plate glass panes and aluminum window frames. In addition, a regular glass pane was tested for comparison with the tempered glass.

These tests were performed at ARRADCOM in April and June of 1975 and were conducted in three stages. In the first stage, the strength of the aluminum window frame was tested independently of the glass; while in the second stage, tempered and regular glass panes were loaded to failure in a specially designed wooden frame to determine ultimate glass capacities independently of the aluminum frame. In the last stage, a full assemblage of aluminum window frame and tempered glass was tested to evaluate the static strength of the combined unit.

The aluminum window frame attachment to a building and the latch closure mechanism were also tested under a simulated rebound condition which would be produced as a result of an explosion. Modifications to strengthen the window frames were made as the test program progressed.

This section describes the materials tested, the test procedure and the test setup, and presents and discusses the results of each test. The engineering drawings in Appendix A may be referred to for additional details of the test design. A further evaluation of the static test results in conjunction with the dynamic test results is presented later in the report.

### Regular and Tempered Glass

Regular and tempered safety glass panes were tested under uniform loading conditions. The size of the glass in both cases was 0.72 m x 1.10 m x 6.35 mm (28-3/8 in x 43-1/4 in x 1/4 in). The tempered glass met the American National Standards Institute (ANSI) Specifications Z97.1 1972. It was manufactured by PPG Industries, Pittsburgh, Pennsylvania and marketed under the trade name of "Herculite". The regular glass pane tested was cut from a glass pane on hand at ARRADCOM, which was not a tempered or special safety glass.

### Aluminum Window Frame

The aluminum window frames tested were of two different sizes:

1. Small size frames with outer dimensions of 0.72 m x 1.10 m (28-3/8 in x 43-1/4 in).

2. Large size frames with outer dimensions of 0.84 m x 1.22 m (33-1/4 in x 48 in).

The small size window frames were used to test the strength of the frames; whereas the large size frames were used to test the assembly of the frame and the glass. The frames were aluminum-projected windows, Series 7500, PA-2 HP, manufactured by the Loxcreen Company, Inc., West Columbia, South Carolina, and furnished by Pipes and Drafts, Inc., West Columbia, South Carolina. The frame consisted of two parts: an outer stationary part which is attached to the building, and an inner movable part containing the glass, which opens outward. The frame was a standard conventional design with no strengthening for blast resistance. A photograph of the frame is shown in Figure 1.

Wooden Frame

A plan view and details of the wooden frame designed for the glass tests are shown in Figure 2. It was anticipated that the aluminum window frame, although adequate for conventional wind load design, would fail before the tempered glass reached its ultimate capacity. This was later shown to be true. The wooden frame was designed to test the strength of the glass alone by providing a continuous rigid support. It was felt that distortions and deviations from straightness in the aluminum frame, resulting from the high intensity loading, would induce stress concentrations in the glass edges during the loading process and cause chipping or failure of the glass before its true capacity was attained.

General Test Setup

The basic steel framework shown in Figure 3 was designed to support the small size aluminum window frame in the first stage of testing. The framework provided support along the long sides of the frame which represented the head and sill of the window frame. The steel framework was later modified to accommodate the large size window frame and glass assembly. Top and bottom flanges of the main beam of the supporting steel framework were cut on one side to avoid interference with the vertical post of the Instron Testing Machine. The testing machine with its recorder unit is shown in Figure 4. Efforts were made to distribute the load applied by the testing machine as uniformly as possible to the window frame, glass, and the assembly of the window frame and glass, in order to simulate a blast-loading condition.

In the tests of the small aluminum window frame, a 6.35-mm (1/4-in) thick steel plate was used in lieu of a glass pane. The load was transferred by two built-up bearing structures and two 25-mm (1-in) thick plywood planks. The top wooden structure was constructed by nailing 3-in x 6-in pieces together and using blocking pieces perpendicular to the 3-in x 6-in pieces. The bottom unit was constructed from 2-in x 4-in pieces and blocking. One plywood plank was placed between the two wooden structures, and the other was placed below the bottom wooden structure. A 25-mm (1-in) thick polyurethane pad was added between the lower plywood plank and the 6.35-mm (1/4-in) steel plate. This test setup is shown in Figure 5.

The test setup was similar for testing the glass panes. The glass was mounted in the wooden frame illustrated in Figure 2. To provide additional cushioning between the glass and the 25-mm (1-in) thick polyurethane pad, fibre pads with a total thickness of 0.15-m (6-in) were added as shown in Figure 6. For the aluminum window frame and tempered glass assembly tests, the glass was mounted in the large aluminum window frame. As shown in Figure 7, additional fibre pads were used to assure a uniform distribution of the load in the test.

Figure 8 is a cross-section illustrating the glass (or steel plate) held in place by the glazing bead and mounted in the aluminum frame, which was in turn supported by the steel test framework. The glazing bead is snapped in place and held by notches in the frame. A 3.18-mm (1/8-in) thick glazing tape was used as the glazing compound.

Still photographs were taken before and after each test to document the test setup and record the damage, in addition to hand measurements and visual observation. The loads applied to each test specimen were recorded by the Instron Testing Machine.

## Aluminum Window Frame Tests

Five tests were performed on the small aluminum window frame, three of which tested the frame in direct loading and two in rebound or reverse loading. These tests are described below:

### Test No. 1 - Direct Loading

The load was transferred from the machine to the window frame by a 6.35-mm (1/4-in) thick steel plate (see Figure 5 for general test setup). The combined weight of the wooden bearing structure and the steel plate was 57 kg (125 lb). This weight was added to the load registered by the testing machine to obtain the total applied load.

In this test, the glazing bead holding the steel plate in place was deformed and popped out of the notches, causing the steel plate to fall out (Fig 9). The deformed glazing bead is illustrated in Figure 10. The failure load, expressed as a uniform pressure applied to the loaded area of the plate, was 19.79 kPa (2.87 psi).

Test No. 2 - Direct Loading Using Intermittent Supports

Aluminum window frame installations in conventional buildings utilize supports at two or three points along the head and sill (long sides) of the frame. An example of such supports is the use of metal straps attached to the frame and nailed to wood blocking or other building framework. It was felt that this type of attachment is not adequate to resist the direct and rebound blast loads. Test No. 2 was designed to evaluate intermittent supports, a condition between a continuous support (Test No. 1) and point supports. These intermittent supports were provided by clamping one 86-mm wide x 6.35-mm thick x 0.18-m long (3-3/8-in wide x 1/4-in thick x 7-in long) plate at each end, and an 86-mm wide x 6.35-mm thick x 0.31-m long (3-3/8-in wide x 1/4-in thick x 12-in long) plate in the middle of the long sides of the window frame support (Fig 11). The total pressure resisted by the window frame when the glazing bead popped out was 19.37 kPa (2.81 psi), which was about the same failure load as that for Test No. 1. From this test, it was concluded that there was no reduction in the frame capacity under direct loading, due to the intermittent supports.

Test No. 3 - Direct Loading with Strengthened Window Frame

From the first two tests, it became obvious that the glazing bead was popping out and thereby limiting the capacity of the frame. To remedy this inherent weakness, three screws (one at each end and one in the middle) were used to secure each glazing bead to the window frame (Fig 12). The test setup was identical to Test No. 1 (Fig 5). The failure load more than doubled compared to Test No. 1 and reached a pressure of 41.02 kPa (5.95 psi).

Test No. 4 - Reverse Loading on Window Latch

This test was conducted to simulate the rebound effects due to a blast loading. The frame was turned over to apply the load from the opposite direction. In this configuration, the glass rests directly against the frame and hence, the reaction is not transferred through the glazing bead, as it is under direct loading. Thus, distortion of the glazing bead is not a problem for reverse loading.

The latch did not fail, but excessive deformation in the vicinity of the latch caused the latch to open at a pressure of 7.10 kPa (1.03 psi). Figures 13 and 14 show the test setup before and after the test, respectively. It is felt that this condition does not represent a true failure since it would merely cause the window to open outward but still remain attached to the hinges. However, if no blast pressure leakage can be permitted in a particular building design, or total closure of the windows is required, it will be necessary to modify the latching mechanism to provide at least the rebound strength of the frame.

Test No. 5 - Reverse Loading on Window Frame

To test the capacity of the window frame and its connections to the building for rebound loading, it was necessary to render the latch mechanism inoperable. This was achieved by connecting the movable part of the frame to the stationary part with 6.35-mm (1/4-in) diameter bolts spaced at 0.1 m (4 in) on center. This modification prevented the window from opening.

The window frame was attached to the supporting structural steel frame using a structural steel angle. Attachment of the window frame to the angle was accomplished by 12 blind rivets along each long side of the frame (Fig 15). The locations of the rivets correspond to the intermittent supports of Test No. 2. It was observed from this test that the capacity of blind rivets is considerably greater than that of the window frame. There was no well defined failure load; but at 19.37 kPa (2.81 psi), the test was stopped due to excessive deformation of the frame. This load was the same as the failure load of the unmodified frame under direct loading (Tests Nos. 1 and 2).

Tempered and Regular Glass Tests

Tempered and regular glass panes mounted in a wooden frame (Fig 2) were tested. Three tests were performed, two on tempered glass and one on regular glass, as described below:

Test No. 6 - Tempered Glass in Wooden Frame

As previously indicated, glass tests were performed to determine the strength of the glass independent of the aluminum frame. The load was increased gradually until the glass broke (see Figure 6 for the test setup). The wooden frame and broken glass are illustrated in Figure 16. The failure pressure was 59.16 kPa (8.58 psi). It is seen that tempered glass breaks into many small pieces which is characteristic of safety glass. Some splitting of the wooden frame occurred; however, it is felt that this did not contribute significantly to the glass failure.

Test No. 7 - Tempered Glass in Wooden Frame

This was a confirmatory test identical to Test No. 6. The failure pressure was 57.23 kPa (8.30 psi) which verified the capacity of the tempered glass.

Test No. 8 - Regular Glass in Wooden Frame

The failure pressure in this test was only 4.48 kPa (0.65 psi). The breakage of the regular glass produced large jagged pieces, shown in Figure 17, which are considered to be more hazardous to personnel than the small fragments associated with the breakage of tempered glass. The test setup for this test was similar to that for the tempered glass (Fig 6).

Tempered Glass in Aluminum Frame Tests

Three tests as described below were performed on tempered glass mounted in large aluminum window frames:

Test No. 9 - Direct Loading

In this test, the glazing bead snapped out at a pressure of 7.03 kPa (1.02 psi) with no damage to either the glass or the window frame. This was considered a premature failure due to an inadequately secured glazing bead. Figure 7 illustrates the test setup.

Test No. 10 - Direct Loading

Care was taken to fit the glazing bead properly in the frame. The load was increased to a pressure of 15.38 kPa (2.23 psi) when the glass broke. The glazing bead remained in place; however, it was concluded that the failure of the glass was due to distortion of the glazing bead. It is noted that the failure load was about 80 percent of the load at which the glazing bead popped out in Tests Nos. 1 and 2.

Test No. 11 - Direct Loading with Strengthened Window Frame

The glazing beads were secured and stiffened by attaching them to the window frame with three screws in each bead (Fig 12) similar to Test No. 3. The failure occurred at 30.54 kPa (4.43 psi) due to deformation of the glazing bead, but developed a capacity twice that of Test No. 10. Figure 18 shows the failure of the glass and indicates the location of the screws. The screws prevented popping out of the glazing beads; however, it is felt that with the provision of an additional screw along each long

side of the frame, deformation of the glazing bead would be further reduced. This modification was used in the dynamic test of the strengthened frame.

Summary of Static Test Results

Table 1 presents a summary of the results of the static tests (Nos. 1 through 11). The key results are summarized below. These results are further evaluated later in the report in conjunction with results of the dynamic load tests.

1. The capacity of the windows tested was controlled by the capacity of the aluminum frame.

2. The direct load capacity of the aluminum frame without modification was approximately 20 kPa (2.9 psi) which was controlled by the distortion and popping out of the glazing bead.

3. Strengthening of the aluminum frame (glazing bead secured with screws) doubled the direct load capacity to about 40 kPa (5.9 psi).

4. The capacity of the tempered glass, independent of the aluminum frame, was approximately 58 kPa (8.5 psi).

5. The capacity of the tempered glass mounted in the aluminum frame without modification was about 15 kPa (2.2 psi), in which case failure of the glass was initiated by distortions of the glazing bead.

6. The capacity of the tempered glass mounted in the strengthened aluminum frame was doubled to about 30 kPa (4.4 psi). These results are also consistent with the capacity of the strengthened small aluminum frame.

7. The capacity of window latch in a simulated rebound mode was about 7 kPa (1.0 psi) and the capacity of the frame in rebound was about 19 kPa (2.8 psi). The rebound mode is not considered to be critical since the flexibility and release of the latch would tend to reduce the rebound response. In addition, any glass breakage would be towards the exterior of the building. However, if it is necessary that the windows remain closed, modification of the latch design would be required.

8. The capacity of the regular glass mounted in a rigid wooden frame was about 5 kPa (0.7 psi), which is about 10 times less than that of the tempered glass. It is noted that only one regular glass test was performed and the specimen used was of unknown origin.

## DYNAMIC LOAD TESTS

### General

Dynamic load tests were performed on regular and tempered plate glass at White Sage East Test Facility Range of Dugway Proving Ground (DPG), Utah, under the direction of ARRADCOM. Test Series I, consisting of five tests, was performed in June and September of 1975. The tests were completed when Test Series II, consisting of seven tests, was conducted in February 1976. Four out of these latter seven tests involved window frames and glass and hence, are covered in this report. The test specimens included glass and frames of the same type and size as those of the static tests in order to compare the results of the dynamic tests with the static tests. In addition, thicker glass and a larger glass pane size were tested.

Regular plate glass and tempered safety glass panes, mounted in wooden frames, were tested. Tempered glass panes, mounted in aluminum frames, were also tested. The test structures used to support the test specimens consisted of two wooden box structures (A and B) shown in Figures 19 and 20. Blast loads were produced by exploding propellants and Composition C-4 used as explosive and booster, respectively. References 1 and 2, which describe the two test series, were prepared by Dugway Proving Ground for documentation purposes and were used freely in the preparation of this section of the report.

### Regular and Tempered Glass

Regular glass was of no specific brand; whereas the tempered glass met the requirements of ANSI Specification Z97.1 1972. "Herculite" brand tempered glass manufactured by PPG Industries, Pittsburgh, Pennsylvania, and "Durasafe" brand tempered glass manufactured by Falconer Plate Glass Corporation, Falconer, New York, were tested. The Herculite tempered glass was also tested in the static tests. Table 2 summarizes the types and sizes of glass and frames that were tested.

### Wooden Frame

Two sizes of wooden window frames were used corresponding to the small and large size glass panes tested (Table 2). Mounting of the glass inside the frame was similar to that of the static tests and provided a rigid supporting frame to test the capacity of the glass independent of an actual metal frame. Additional

wooden frames were constructed, fitted with glass, and were available at the test site to replace any broken windows. A cross-section of the wooden frame mounted in the test structure is illustrated in Figure 21.

## Aluminum Window Frame

The aluminum window frame for the static tests had an inner movable and an outer stationary piece (Fig 1). The movable piece contains the glass. The stationary piece was removed from the frame for the dynamic tests since the box structure opening was not large enough to accommodate the entire window frame. Elimination of the outer frame was not considered to have a significant effect on the test results since the frame behavior in the static tests indicated that the outer frame was not a factor in the frame/glass capacity.

The glazing bead was snapped into place in two tests; whereas in two other tests, it was fastened to the frame using screws. The screw fastening was provided to restrain the glazing bead and thereby increase the glass capacity, as indicated by the results of the static tests. A cross-section of the aluminum window frame fitted into the wooden structure is illustrated in Figure 22. Only 6.35-mm (1/4-in) thick Durasafe tempered glass was tested in aluminum frames.

## Test Structures

Two box-like structures constructed of wood (Figs 19 and 20) were used as support structures for the dynamic tests. Each structure was 4.88 m long, 2.13 m wide and 2.44 m high (16 ft long, 7 ft wide and 8 ft high), and was designed to withstand approximately 27.6 kPa (4 psi) overpressure. One of the test structures, designated as Structure A, was designed to accommodate two large and three small glass panes. The orientation of Structure A relative to the blast was such that the two large and two small glass panes were subjected to side-on pressures and the remaining small panel to reflected blast pressures. The other structure, designated as Structure B, was identical to Structure A except that the opening facing the blast wave was designed to accept a cold-formed steel panel. The roof of each structure was also designed to accept a cold-formed steel panel. In Test Series I, the cold-formed steel panels were not provided; but Test Series II did include steel panels on the roof of each structure and on the front face of Structure B. The results of the dynamic load tests on cold-formed steel panels are presented in a separate report.

The engineering drawings for the test structures are reproduced in Appendix A. A photograph of the interior framework taken during

construction of one of the test structures is shown in Figure 23. The two structures were built in the shop and pulled to the test site using a tractor (Fig 24). They were positioned on the test site, and the window openings were labeled for identification as illustrated in Figure 25.

Explosives

The explosives used in this test program were M26E1 artillery-type propellant as the primary charge and Composition C-4 as the booster charge (Fig 26). The M26E1 propellant is multi-perforated with a web of 0.97 mm (0.038 in). The combined weight of the primary charge and the booster in each test was approximately 900 kg (2,000 lb) with the booster weighing approximately 20 kg (45 lb). The propellant used was delivered to the site in fibreboard shipping containers with a net weight of approximately 73 kg (160 lb) each.

The total explosive charge was held in a 1-m (39-in) cube container (Fig 27) constructed from 19-mm (3/4-in) thick plywood, two by fours, and strengthened by 13-mm (1/2-in) wide steel strips. The Composition C-4 booster was primed with two electric detonators, which initiated detonation of the entire charge as illustrated in Figure 28.

The structures were located based on blast pressure predictions developed from TNT equivalency tests performed on M26E1 propellant by the IIT Research Institute for ARRADCOM (Ref 3).

Instrumentation

Instrumentation for the dynamic tests consisted of a Susquehanna ST-7 transducer housed in an integral ballistic probe to measure side-on blast overpressures. Each instrument was mounted in an adjustable pipe stand, as illustrated in Figure 29, to facilitate positioning and orientation. Five instruments were used to form a blast line from which the overpressure at each structure was determined. The transducers were connected to Biomation transient-wave recorders and Quad-Systems recording instruments for collecting and recording pressure-versus-time data.

Photographic Coverage

Two high-speed motion picture cameras operating at speeds up to 1,000 frames per second were used to document any unusual effects or transient motions of the test structures produced by the explosion and the resulting blast loads. In addition, still photographs were taken before and after each test to document

the test setup and to record glass breakage and damage to the test structure and aluminum frame.

## General Description of Tests

There were five tests performed in Test Series I and four tests in Test Series II. The test structures were positioned on opposite sides of the blast line at predetermined distances from the explosive charge to achieve the desired blast loading on the glass panes. The explosive charge weight and location of ground zero were held constant for all the tests, with the test structures relocated to vary the overpressure level. Figure 30 illustrates the orientation and general location of the gages, test structures and windows with respect to ground zero.

In the first test series, only the peak positive pressures were obtained; whereas in the second test series, pressure-time histories were recorded. Tables 3 and 4 summarize the blast overpressure data for Test Series I and II, respectively. Since the amount of explosive used in both series and in each test was essentially the same, it was felt that the pressure-time records from Test Series II would also be representative for Test Series I. Table 5 presents a summary of the dynamic test results for both test series and lists the types of glass panes tested, the blast overpressures experienced in Structures A and B, and the extent of glass damage.

After each detonation, the glass panes and test structures were inspected for damage, diameter and depth of resulting crater were measured, and the test area was examined for residual propellant and other damage. Still photographs were also taken to document damage and glass breakage.

Preparation of the site and the test structures for each subsequent test included replacing the broken glass panes, repairing the test fixtures, filling the crater created by the explosion, and leveling ground zero. The blast gages were fixed into new positions and the measuring instruments were checked and calibrated for a new pressure range. The test structures were moved closer to ground zero after each test in order to subject the windows to gradually increasing overpressures.

## Test Series I

Both Herculite and Durasafe tempered glass in wooden frames were tested in this series. These tests are described below:

## Test No. 1 - Tempered Glass in Wooden Frame

Structure A contained three 6.35-mm (1/4-in) and two 9.52-mm (3/8-in) thick glass windows and Structure B had two 6.35-mm (1/4-in) and two 9.52-mm (3/8-in) thick glass windows. All window glass for this test was Herculite tempered glass. The expected blast overpressures were 6.9 kPa (1.0 psi) at Structure A and 13.8 kPa (2.0 psi) at Structure B. However, the actual blast pressures produced by the explosion were 5.5 kPa (0.8 psi) and 9.7 kPa (1.4 psi) for Structures A and B, respectively. There was no resulting damage to the glass.

## Test No. 2 - Tempered Glass in Wooden Frame

Structures A and B, with the same glass specimens as Test No. 1, were moved closer to ground zero to increase the overpressure level. The blast pressures recorded were 17.2 kPa (2.5 psi) and 22.8 kPa (3.3 psi) for Structures A and B, respectively, compared to predicted cverpressures of 13.8 kPa (2 psi) for Structure A and 24.1 kPa (3.5 psi) for Structure B. Again, there was no damage to the glass.

## Test No. 3 - Tempered Glass in Wooden Frame

The Herculite glass panes in Structure A were replaced with Durasafe panes and the structure was left at the same location as that of Test No. 2. The Herculite glass was left in Structure B and the structure was relocated to obtain an expected overpressure of 27.6 kPa (4 psi). Actual overpressures were 8.3 kPa (1.2 psi) and 29.6 kPa (4.3 psi) on Structures A and B, respectively. There was no damage to any of the windows.

## Test No. 4 - Tempered Glass in Wooden Frame

None of the windows suffered any damage in this test. Both structures, with the same glass specimens as those of Test No. 3, were moved closer to ground zero, each at the same distance from ground zero and symmetrical about the gage line. The recorded blast overpressure at the location of th structures was 44.8 kPa (6.5 psi) compared to an estimated pressure of 31.0 kPa (4.5 psi). The validity of the high measured pressure is questionable; however, based on the overpressure recorded in Test No. 5 at the same location, it is assumed that a pressure of at least 30.3 kPa (4.4 psi) occurred.

Test No. 5 - Tempered Glass in Wooden Frame

Since there was no glass breakage in the first four tests, it was suspected that an air cushion may have developed as the glass deflected between the glass pane and the plywood plank backing which could have the effect of reducing the net loading on the glass. The original glass pane and the plywood backing can be seen in Figure 20. To alleviate this possible air-cushion effect, two holes were cut in the small window backings and three holes were made in the large window backings. The size of each hole is 0.18 m (7 in). As shown in Figures 31 and 32, the holes were cut in the plywood and in the styrofoam padding which was placed in between the glass and plywood to retain broken glass fragments.

A large pane of Durasafe glass, 6.35 mm (1/4 in) thick, in Window No. 4 of Structure A, shattered in the test. The blast overpressure recorded was 30.3 kPa (4.4 psi) which is almost the same as the anticipated pressure of 31 kPa (4.5 psi). Broken glass is shown in Figure 33 and the damage to the window backing is illustrated in Figure 34. The glass breakage into many small pieces is similar to that which occurred in the static tests (Fig 16).

Test Series II

In this test series, regular glass in wooden frames and Durasafe tempered glass in aluminum frames were tested. Regular glass was tested in Structure A and Durasafe tempered glass in aluminum frames was tested in Structure B. Only one window position in Structure B was used in this test series.

Test No. 1 - Regular Glass in Wooden Frame and Tempered Glass in Aluminum Frame

There were two 6.35-mm (1/4-in) and three 9.52-mm (3/8-in) regular glass windows in Structure A. Structure B had a Durasafe window in a standard aluminum frame. The expected pressures were 3.4 kPa (0.5 psi) and 13.8 kPa (2.0 psi) for Structures A and B, respectively. The actual pressures obtained were 2.07 kPa (0.3 psi) for Structure A and 5.89 kPa (1.0 psi) for Structure B, which are considerably lower than the expected values. The blast load durations were 42 ms for Structure A and 48 ms for Structure B. There was no damage to any of the windows.

Test No. 2 - Regular Glass in Wooden Frame and Tempered Glass in Aluminum Frame

All window specimens in this test were the same as for Test No. 1 and the structures were moved a little closer to ground zero in a second attempt to obtain pressures of 3.4 kPa (0.5 psi)

and 13.8 kPa (2.0 psi) for Structures A and B, respectively. The actual overpressures recorded were 2.14 kPa (0.31 psi) and 8.27 kPa (1.2 psi) for Structures A and B, respectively. The blast duration was 43 ms for Structure A and 50 ms for Structure B. The Durasafe glass mounted in the standard aluminum frame broke in this test. The aluminum frame was also damaged. The glazing beads holding the glass were compressed and deformed, and could not be reused. Based on the static test results, it is theorized that the failure of the frame caused the glass breakage. The pressure-time curve for Gage No. 2 is illustrated in Figure 35. The shape of this curve is typical of the other test records.

Test No. 3 - Regular Glass in Wooden Frame and Tempered Glass in Strengthened Aluminum Frame

Structure A, with the same regular glass panes as those in Tests Nos. 1 and 2, was relocated closer to ground zero at an expected overpressure level of 4.8 kPa (0.7 psi). Since Window No. 2 of Structure B broke in the previous test at 8.27 kPa (1.2 psi), using a standard aluminum frame, a strengthened frame was provided by securing the glazing bead to the frame with three screws along each short glazing bead as was done in the Static Tests, and four screws along each long glazing bead (refer to Figure 22). Structure B was located at an expected overpressure level of 20.7 kPa (3.0 psi). The actual pressures realized were 5.38 kPa (0.78 psi) and 15.86 kPa (2.3 psi) for Structures A and B, respectively. The load durations were 44 ms for Structure A and 50 ms for Structure B. No damage was done to the tempered glass in the strengthened frame; however, one small pane and one large pane of regular glass were broken in Structure A. A post-test photograph of Structure A is shown in Figure 36. A close-up view of the small window in Figure 37 provides details of the jagged nature of the broken regular glass compared to the fine pieces produced by broken tempered glass (Fig 33). This glass breakage is also similar to that which occurred in the static test of regular glass as shown in Figure 17.

Test No. 4 - Tempered Glass in Strengthened Aluminum Frame

Since the blast capacity of the regular glass was reached in Test No. 3, no further testing of regular glass was performed; therefore, Structure A was not used in Test No. 4. Structure B with the same strengthened aluminum frame specimen as that of Test No. 3 was moved closer to ground zero at an expected blast overpressure of 27.6 kPa (4.0 psi). The actual recorded pressure was 21.37 kPa (3.1 psi) and the window was broken. The deformed aluminum window frame and tempered glass breakage are shown in Figure 38.

Summary of Dynamic Test Results

Table 5 presents a summary of the results of the dynamic tests (Test Series I, Test Nos. 1 through 5 and Test Series II, Tests Nos. 1 through 4). The significant information derived from these tests are summarized below. These results, in conjunction with the static load test data, are further evaluated in the following section:

1. The blast capacity of the windows tested was controlled by the capacity of the aluminum frame.

2. The blast capacity of the 6.35-mm (1/4-in) thick tempered glass (large pane) independent of the aluminum frame was about 30 kPa (4.4 psi). There was no breakage of the small panes of 6.35-mm (1/4-in) thick tempered glass subjected to blast pressures up to 30 kPa (4.4 psi).

3. The blast capacity of the 6.35-mm (1/4-in) thick tempered glass mounted in the aluminum frame without modification was between 6.9 kPa (1.0 psi) and 8.3 kPa (1.2 psi).

4. The blast capacity of the 6.35-mm (1/4-in) thick glass mounted in the strengthened aluminum frame was more than doubled to between 16 kPa (2.3 psi) and 21 kPa (3.1 psi).

5. There was no breakage of the 9.52-mm (3/8-in) thick tempered glass mounted in a rigid wooden frame subjected to blast pressures up to 30 kPa (4.4 psi).

6. The blast capacity of the 6.35-mm (1/4-in) thick regular glass (large pane) mounted in a rigid wooden frame was between 2.1 kPa (0.3 psi) and 5.4 kPa (0.8 psi). There was no breakage of the small panes of 6.35-mm (1/4-in) thick regular glass subjected to blast pressures up to 5.4 kPa (0.8 psi).

7. The blast capacity of 9.52-mm (3/8-in) thick regular glass mounted in a rigid wooden frame was between 4.2 kPa (0.6 psi) and 11 kPa (1.6 psi). This window was on the front face of the box structure and these pressures are calculated reflected pressures which would have an effective duration considerably less than that of the incident pressure.

## EVALUATION OF TEST RESULTS

### General

This section compares and discusses the results of the static and dynamic glass and frame tests presented in the previous sections. In addition, data relative to conventional glass capacity for wind loads and data from blast tests performed by others are compared with the test results. Recommendations for design criteria based on the evaluation of the test data are also presented.

### Comparison of Static and Dynamic Test Results

Tables 1 and 5 presented a summary of the test results for the static and dynamic tests, respectively. In order to compare these results, it is necessary to consider the dynamic load factors associated with the blast load tests. The dynamic load factor is the ratio of the required static resistance of the element to the peak blast overpressure. This ratio is a function of the natural period of vibration (of the glass pane), duration of the blast load, and ductility ratio (ratio of maximum deflection to peak elastic deflection). Assuming elastic action, upper bounds of the dynamic load factors were computed (Chapter 6, Ref 4) as summarized below. An equivalent triangular blast load duration of 40 ms was used based on the durations recorded in Dynamic Test Series No. 2 (Table 4). For larger explosive weights, dynamic load factors would be somewhat greater. In calculating the period of vibration of the glass, a weight for the 6.35-mm (1/4-in) thick glass of 15.82 kg/sq m (3.24 psf) and a modulus of elasticity of 69 x $10^6$ kPa ($10^7$ psi) were used.

| Glass Pane* | Dynamic Load Factor (ms) |
|---|---|
| HS2, DS2, RS2 FDS2, FFDS2 | 1.70 |
| HS3, RS3 | 1.75 |
| HL2, DL2 | 1.30 |
| HL3 | 1.50 |

* Refer to Table 2 for glass pane designations

Table 6 is a summary of the pressures at which failure occurred for the aluminum frame, glass in a wooden frame and glass in an

aluminum frame test specimens. The static pressures have been divided by the appropriate dynamic load factor for comparison with the dynamic blast capacities. It is seen from Table 6 that there is very good correlation between the static and dynamic test results, particularly for the tempered glass and tempered glass in aluminum frame tests. The failure load of the regular glass in the dynamic tests was considerably greater than that of the static test. However, as discussed previously, only one regular glass pane of unknown origin was tested in the static test. Based on the dynamic test results, the blast capacity of tempered glass is about 5 to 6 times that of regular glass.

With regard to rebound, the static capacity of the aluminum frame under reversed loading (Table 1, Test No. 5) was about the same as that under direct loading (Table 1, Tests Nos. 1 and 2). This is more than adequate since the response in rebound would be less than that in direct loading. For the dynamic tests, rebound was automatically accounted for by the blast loadings.

## Comparison of Test Results with Other Data

### Blast Tests on Regular Glass

Pertinent data reported from the results of ESKIMO II and ESKIMO III high explosive tests (Refs 5 and 6) are summarized in Tables 7 and 8. These tests were conducted on standard (untempered) plate and sheet glass panes mounted in fixed and non-fixed frames. Pane sizes were 1.14 m by 1.14 m (45 in by 45 in); 1.07 m by 0.51 m (42 in by 20 in); 0.86 m by 1.22 m (34 in by 48 in); and 1.22 m by 2.29 m (48 in by 90 in). Panes were approximately 6.35 mm (1/4 in) and 3.18 mm (1/8 in) thick. All of the windows faced ground zero and were, therefore, subjected to reflected overpressure. Based on the ESKIMO III test data, the blast capacity for regular glass lies between 3.03 kPa (0.44 psi) and 5.72 kPa (0.83 psi). The ESKIMO III data suggests that the upper limit is closer to 4.13 kPa (0.60 psi). The ARRADCOM failure load of 5.38 kPa (0.78 psi) (Table 6) recorded for the dynamic test on regular glass falls within this range and represents good correlation with the ESKIMO II and III data.

### Wind Load Capacities

For conventional design, most glass manufacturers publish data for glass capacity under wind loading. Such data for Herculite tempered glass (obtained from Ref 7) is illustrated in Figure 39. The large glass size tested has an area of about 1.86 sq m (20 sq ft). For this area and 6.35-mm (1/4-in) thick glass,

the wind load capacity is approximately 12.5 kPa (1.80 psi or 260 psf) with a safety factor of 2.5. The capacity with a safety factor of unity would be 2.5 x 12.5 kPa or 31.2 kPa (4.5 psi). This value is almost identical to the failure load of 30.3 kPa (4.4 psi) from Table 6, although some adjustment would have to be made for the relative dynamic load factor between the blast and wind load condition.

Figure 40 shows corresponding wind load capacity data for regular glass (Ref 7). In this case, for 6.35-mm (1/4-in) thick glass and 1.86-sq m (20-sq ft) area, the wind load capacity is 2.73 kPa (0.396 psi or 57 psf) with a safety factor of 2.5. This corresponds to a capacity of about 6.9 kPa (1.0 psi) for a safety factor of unity, which is a little less than one-fourth the value for tempered glass. This value is greater than the failure load of 5.38 kPa (0.78 psi) from Table 6. It should be noted that a safety factor of unity in the glass industry terminology corresponds to the wind load at which the probable number of panes that will break is 50 percent of the number subjected to the load. For a safety factor of 2.5, the probable number of panes that will break reduces to 8 out of 1,000 subjected to the load.

## Recommended Design Criteria

In order to provide facility designers with specific guidelines for protective window designs used in buildings at Army Ammunition Plants, the design criteria in Tables 9 and 10 have been prepared. These tables are described below.

Table 9 presents the peak design blast pressure for various blast load durations versus glass type and thickness. The peak pressure is either the incident or reflected pressure, depending on the orientation of the window with respect to the blast wave. The blast load duration is the duration of an equivalent triangular blast load. Procedures for calculating equivalent triangular load duration are described in Chapter 4 of Reference 4.

The peak pressures in Table 9 are maximum design values for glass panes mounted in rigid window frames, where continuous support for direct load and rebound is provided for the glass similar to that provided by the wooden frames used in the static and dynamic tests (Figs 2 and 21). In the tests performed with glass mounted in aluminum window frames, the capacity of the windows was greatly limited even where a strengthened frame was used. It will be necessary to evaluate the particular frame design selected for use since there are considerable variations in frame types and details. Depending on the design overpressure level, the frame may require modification or it may be necessary to specify a special frame

design which will provide sufficient strength and rigidity to develop the capacity of the glass. Table 10 presents the maximum blast pressure capacities for glass mounted in aluminum window frames of the type tested. Where this type of frame is used, the lower value of the peak pressure obtained from either Table 9 or 10 should be used.

The design criteria presented in Tables 9 and 10 are applicable to glass areas of 1.86 sq m (20 sq ft) or less which was the range covered in the tests. As indicated by the strength data for wind loading in Figures 39 and 40, the glass capacity reduces considerably with increased glass area, although this reduction may be mitigated due to reduced dynamic load factors associated with larger glass panes subjected to short duration blast loads. For Army Ammunition Plant buildings, windows larger than 1.86 sq m (20 sq ft) would generally not be required nor desirable.

The blast pressure capacities in Tables 9 and 10 were developed based on the results of the static and dynamic tests and consideration of comparisons with other data. The equivalent triangular load duration for the tempered and regular glass tested in the dynamic tests was approximately 40 ms for incident pressure and 20 ms for reflected pressure. Blast capacities for the range of durations in Tables 9 and 10 were extrapolated based on the relative dynamic load factors. Blast capacities for 3.18-mm (1/8-in) thick glass were extrapolated from the test results based on relative strength under wind loading (Figs 39 and 40) and relative dynamic load factors. The recommendations (see following section) of this report include testing of 3.18-mm (1/8-in) thick glass and it is expected that the results will verify or establish the conservatism of the criteria presented for this thickness.

## CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

The results of these tests indicate a maximum blast capacity of 30.3-kPa (4.4-psi) incident overpressure from 900 kg (2,000 lb) of explosives for 6.35-mm (1/4-in) thick tempered glass panes mounted in rigid frames with a glass area of 1.86 sq m (20 sq ft) or less. For tempered glass mounted in aluminum window frames, the blast capacity was reduced due to frame distortions to 8.27 kPa (1.2 psi) for standard frames and 17.9 kPa (2.6 psi) for strengthened frames. Thus, the window frame is the critical element and it will be necessary, in many cases, to provide special frame designs to develop the blast capacity of the glass.

The use of regular (untempered) glass is limited to blast overpressures of about 3.4 kPa (0.5 psi). In addition, the size and shape of the glass fragments resulting from glass breakage of regular glass would represent a greater hazard to personnel than that of tempered glass.

Thick glass, 9.52 mm (3/8 in), is considerably stronger than 6.35-mm (1/4-in) thick glass and would generally not be required except for higher pressure levels.

### Recommendations

It is recommended that the design criteria developed from the test results as presented in Tables 9 and 10 be utilized in the design of blast-resistant windows for buildings located at Army Ammunition Plants or other explosive manufacturing, storage and inspection facilities.

It is recommended that additional tests be performed to verify the blast capacity of 3.18-mm (1/8-in) thick glass windows.

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## Table 1

### Summary of static test results

| Test No. | Type of Frame | Item tested | Steel plate or glass size* m x m (in x in) | Loaded area sq m (sq in) | Failure load kg (lb) | Failure pressure kPa (psi) | Failure mechanism |
|---|---|---|---|---|---|---|---|
| 1 | Small aluminum | Frame | 0.60 x 0.98 (23-1/2 x 38-1/2) | 0.544 (844) | 1,102 (2,425) | 19.79 (2.87) | Excessive deformation of glazing bead. |
| 2 | Small aluminum | Frame | 0.60 x 0.98 (23-1/2 x 38-1/2) | 0.544 (844) | 1,080 (2,375) | 19.37 (2.[illegible]1) | Excessive deformation of glazing bead. |
| 3 | Small aluminum | Strengthened frame | 0.60 x 0.98 (23-1/2 x 38-1/2) | 0.544 (844) | 2,282 (5,025) | 41.02 (5.95) | Excessive deformation of glazing bead. |
| 4 | Small aluminum | Latch in rebound | 0.60 x 0.98 (23-1/2 x 38-1/2) | 0.544 (844) | 396 (870) | 7.10 (1.03) | Excessive deformation of latch. |
| 5 | Small aluminum | Frame in rebound | 0.60 x 0.98 (23-1/2 x 38-1/2) | 0.544 (844) | 1,080 (2,375) | 19.37 (2.81) | Excessive deformation of frame. |
| 6 | Wooden | Tempered glass | 0.72 x 1.1 (28-3/8 x 43-1/4) | 0.746 (1,156) | 4,509 (9,920) | 59.16 (8.58) | Glass breakage. |
| 7 | Wooden | Tempered glass | 0.72 x 1.1 (28-3/8 x 43-1/4) | 0.746 (1,156) | 4,364 (9,600) | 57.23 (8.30) | Glass breakage. |
| 8 | Wooden | Regular glass | 0.72 x 1.1 (28-3/8 x 43-1/4) | 0.746 (1,156) | 341 (750) | 4.48 (0.65) | Glass breakage. |
| 9 | Large aluminum | Tempered glass and frame | 0.72 x 1.1 (28-3/8 x 43-1/4) | 0.746 (1,156) | 534 (1,175) | 7.03 (1.02) | Glazing bead popped out (premature failure). |
| 10 | Large aluminum | Tempered glass and strengthened frame | 0.72 x 1.1 (28-3/8 x 43-1/4) | 0.746 (1,156) | 1,171 (2,575) | 15.38 (2.23) | Glass breakage due to deformation of glazing bead. |
| 11 | Large aluminum | Tempered glass and strengthened frame | 0.72 x 1.1 (28-3/8 x 43-1/4) | 0.746 (1,156) | 2,330 (5,125) | 30.54 (4.43) | Glass breakage due to deformation of glazing bead. |

* Tests Nos. 1 through 5 used a 6.35-mm (1/4-in) thick steel plate, the remaining tests used 6.35-mm (1/4-in) thick glass.

Table 2

Summary of glass specimens for dynamic tests

| Designation | Length m | Length (in) | Width m | Width (in) | Thickness m | Thickness (in) | Comments |
|---|---|---|---|---|---|---|---|
| RS2 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 6.35 | (2/8) | Regular glass - small |
| RS3 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 9.52 | (3/8) | Regular glass - small |
| RL2 | 1.594 | (62-3/4) | 1.194 | (47) | 6.35 | (2/8) | Regular glass - large |
| RL3 | 1.594 | (62-3/4) | 1.194 | (47) | 9.52 | (3/8) | Regular glass - large |
| DS2 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 6.35 | (2/8) | Durasafe - small |
| DL2 | 1.594 | (62-3/4) | 1.194 | (47) | 6.35 | (2/8) | Durasafe - large |
| FDS2 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 6.35 | (2/8) | Durasafe - small, aluminum frame |
| FFDS2 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 6.35 | (2/8) | Durasafe - small, strengthened aluminum frame |
| HS2 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 6.35 | (2/8) | Herculite - small |
| HS3 | 1.098 | (43-1/4) | 0.721 | (28-3/8) | 9.52 | (3/8) | Herculite - small |
| HL2 | 1.594 | (62-3/4) | 0.194 | (47) | 9.35 | (2/8) | Herculite - large |
| HL3 | 1.594 | (62-3/4) | 1.194 | (47) | 9.52 | (3/8) | Herculite - large |

Table 3

Summary of blast overpressure and duration data - Test Series I

| Test No. | Charge weight kg | (lb) | Gage No. | Distance from charge m | (ft) | Scale distance Z $m/kg^{1/3}$ | $(ft/lb^{1/3})$ | Blast pressure kPa | (psi) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 896 | (1976) | 1 | 61 | (200) | 6.33 | (15.94) | 25.0 | (3.62)[a] |
| | | | 2 | 76 | (250) | 7.88 | (19.92) | 11.0 | (1.59) |
| | | | 3 | 107 | (350) | 11.10 | (27.90) | 7.7 | (1.12) |
| | | | 4 | 152 | (500) | 15.77 | (39.80) | 4.6 | (0.67) |
| | | | 5 | 183 | (600) | 18.98 | (47.80) | 6.3 | (0.92) |
| 2 | 902 | (1988) | 1 | 40 | (130) | 4.14 | (10.34) | 25.1 | (3.64)[a] |
| | | | 2 | 55 | (180) | 5.69 | (14.32) | 18.3 | (2.65) |
| | | | 3 | 85 | (280) | 8.80 | (22.26) | 19.7 | (2.85) |
| | | | 4 | 131 | (430) | 13.56 | (34.20) | 4.2 | (0.61) |
| | | | 5 | 162 | (530) | 16.77 | (42.20) | 6.3 | (0.92) |
| 3 | 891 | (1965) | 1 | 40 | (130) | 4.16 | (10.38) | 68.5 | (9.94)[a] |
| | | | 2 | 55 | (180) | 5.71 | (14.37) | 33.8 | (4.90) |
| | | | 3 | 85 | (280) | 8.84 | (22.35) | 9.5 | (1.38) |
| | | | 4 | 131 | (430) | 13.62 | (34 30) | 3.9 | (0.57) |
| | | | 5 | 162 | (530) | 16.84 | (42.20) | 8.1 | (1.18) |
| 4 | 888 | (1958) | 1 | 47 | (155) | 4.89 | (12.39) | 59.7 | (8.66) |
| | | | 2 | 62 | (205) | 6.45 | (16.39) | 10.6 | (1.54) |
| | | | 3 | 78 | (255) | 8.12 | (20.38) | 14.0 | (2.03) |
| | | | 4 | 123 | (405) | 12.80 | (32.40) | 6.7 | (0.97) |
| | | | 5 | 154 | (505) | 16.02 | (40.40) | b | b |
| 5 | 891 | (1965) | 1 | 47 | (155) | 4.88 | (12.37) | 32.2 | (4.67) |
| | | | 2 | 62 | (205) | 6.44 | (16.37) | 27.1 | (3.93) |

[a] In excess of upper calibration limit (saturated); validity questionable.

[b] No data - Instrumentation malfunction.

Table 4

Summary of blast overpressure and duration data - Test Series II

| Test No. | Charge weight kg | (lb) | Gage No. | Distance from charge m | (ft) | Scale distance Z m/kg$^{1/3}$ | (ft/lb$^{1/3}$) | Blast pressure kPa | (psi) | Blast duration msec |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 893 | (1969) | 1 | 53 | (175) | 5.50 | (13.97) | 26.4 | (3.83) | 31.2 |
| | | | 2 | 79 | (260) | 8.20 | (20.75) | a | | a |
| | | | 3 | 108 | (355) | 11.21 | (28.33) | a | | a |
| | | | 4 | 165 | (540) | 17.13 | (43.10) | a | | a |
| | | | 5 | 244 | (800) | 25.34 | (63.85) | 1.7 | (0.24) | b |
| 2 | 893 | (1969) | 1 | 43 | (140) | 4.47 | (11.17) | 44.8 | (6.50) | 47.5 |
| | | | 2 | 69 | (225) | 7.17 | (17.96) | 13.1 | (1.90) | 44.0 |
| | | | 3 | 98 | (320) | 10.18 | (25.54) | 5.0 | (0.72) | 47.0 |
| | | | 4 | 154 | (505) | 16.00 | (40.30) | 2.6 | (0.38) | 45.0 |
| | | | 5 | 233 | (765) | 24.20 | (61.05) | 1.7 | (0.24) | 42.0 |
| 3 | 888 | (1958) | 1 | 53 | (175) | 5.52 | (13.99) | 16.7 | (2.42) | 44.0 |
| | | | 2 | 79 | (260) | 8.22 | (20.78) | 11.9 | (1.73) | 41.0 |
| | | | 3 | 108 | (355) | 11.24 | (28.38) | 7.3 | (1.06) | 44.0 |
| | | | 4 | 165 | (540) | 17.17 | (43.17) | 3.9 | (0.57) | 43.0 |
| | | | 5 | 244 | (800) | 25.39 | (63.95) | 2.4 | (0.35) | 41.0 |
| 4 | 891 | (1964) | 1 | 38 | (125) | 3.95 | (9.98) | 54.1 | (7.84) | 46.0 |
| | | | 2 | 49 | (160) | 5.09 | (12.78) | 23.4 | (3.40) | 53.0 |
| | | | 3 | 61 | (200) | 6.34 | (15.97) | 12.2 | (1.77) | 51.0 |
| | | | 4 | 79 | (260) | 8.21 | (20.77) | 7.9 | (1.15) | 49.0 |
| | | | 5 | 130 | (425) | 13.51 | (33.95) | 4.3 | (0.63) | 43.0 |

[a] No data - Instrument failure.

[b] No data - Sweeptime too short.

## Table 5

## Summary of dynamic test results

| Series No. | Test No. | Charge weight | | Distance from charge | | | | Pressure | | | | Structure A windows[a] | | | | | Structure B windows[a] | | | | Glass breakage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Structure A | | Structure B | | Structure A | | Structure B | | | | | | | | | | | |
| | | kg | (lb) | m | (ft) | m | (ft) | kPa | (psi) | kPa | (psi) | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | |
| I | 1 | 896 | (1976) | 137 | (450) | 91 | (300) | 5.5 | (0.8) | 9.7 | (1.4) | HS2 | HS3 | HL2 | HL3 | HS2 | HS2 | HS3 | HL2 | HL3 | None |
| I | 2 | 902 | (1988) | 91 | (300) | 70 | (230) | 17.2 | (2.5) | 22.8 | (3.3) | HS2 | HS3 | HL2 | HL3 | HS2 | HS2 | HS3 | HL2 | HL3 | None |
| I | 3 | 891 | (1965) | 91 | (300) | 62 | (205) | 8.3 | (1.2) | 29.6 | (4.3) | DS2 | DS2 | DL2 | DL2 | DS2 | HS2 | HS3 | HL2 | HL3 | None |
| I | 4 | 888 | (1958) | 55 | (180) | 55 | (180) | 44.8[b] | (6.5) | 44.8[b] | (6.5) | DS2 | DS2 | DL2 | DL2 | DS2 | HS2 | HS3 | HL2 | HL3 | None |
| I | 5 | 891 | (1965) | 55 | (180) | 55 | (180) | 30.3 | (4.4) | 30.3 | (4.4) | DS2 | DS2 | DL2 | DL2 | DS2 | HS2 | HS3 | HL2 | HL3 | Struc. A, Window 4 |
| II | 1 | 893 | (1969) | 232 | (760) | 90 | (295) | 2.07 | (0.30) | 6.89 | (1.0) | RS2 | RS3 | RL2 | RL3 | RS3 | - | FDS2 | - | - | None |
| II | 2 | 893 | (1969) | 224 | (735) | 82 | (270) | 2.14 | (0.31) | 8.27 | (1.2) | RS2 | RS3 | RL2 | RL3 | RS3 | - | FDS2 | - | - | FDS2 |
| II | 3 | 888 | (1958) | 110 | (360) | 58 | (190) | 5.38 | (0.78) | 15.86 | (2.3) | RS2 | RS3 | RL2 | RL3 | RS3 | - | FFDS2 | - | - | RL2 and RS3 (Window 5) |
| II | 4 | 891 | (1964) | 76 | (250) | 52 | (170) | - | - | 21.37 | (3.1) | - | - | - | - | | - | FFDS2 | - | - | FFDS2 |

[a] For glass specimen designations, refer to Table 2; for test structure orientation and window numbers, refer to Figure 30.
[b] Results are higher than expected; validity is questionable.

Table 6

Comparison of static and dynamic failure loads

| Item tested | Failure load | | |
|---|---|---|---|
| | Static kPa (psi) | Static/DLF kPa (psi) | Dynamic kPa (psi) |
| Aluminum frame | 19.37 (2.81) | 11.4 (1.7) | - |
| Strengthened aluminum frame | 41.02 (5.95) | 24.1 (3.5) | - |
| 6.35-mm (1/4-in) thick tempered glass in rigid wooden frame | 57.23 (8.30) | 33.7 (4.9) | 30.3 (4.4) |
| 6.35-mm (1/4-in) thick regular glass in rigid wooden frame | 4.48 (0.65) | 2.64 (0.38) | 5.38 (0.78) |
| 9.52-mm (3/8-in) thick regular glass in rigid wooden frame | - | - | 10.8 (1.56)* |
| 6.35-mm (1/4-in) thick tempered glass in aluminum frame | 15.38 (2.23) | 9.1 (1.3) | 8.27 (1.2) |
| 6.35-mm (1/4-in) thick tempered glass in strengthened aluminum frame | 30.54 (4.43) | 18.0 (2.6) | 21.37 (3.1) |

* Short duration reflected pressure.

Table 7

Tests on windows from ESKIMO II event

| $P_{so}^{a}$ kPa (psi) | $P_{r}^{b}$ kPa (psi) | $t_{p}^{c}$ msec | Glass damage |
|---|---|---|---|
| 3.72 (0.54) | 7.58 (1.10) | 158 | All 10 panels broke. 8 of the panels were 6.35 mm (1/4 in ±) thick and 2 were 3.18 mm (1/8 in ±) thick. |
| 2.83 (0.41) | 5.72 (0.83) | 180 | 7 out of 8 panels broke. 6 of the panels were 6.35 mm (1/4 in ±) thick and 2 were 3.18 mm (1/8 in ±) thick. The panel which did not break was 6.35 (1/4 in ±) thick. |
| 1.52 (0.22) | 3.03 (0.44) | 202 | None of the 8 panels [six 6.35 mm (1/4 in ±) and two 3.18 mm (1/8 in ±) broke.] |

[a] $P_{so}$ is the incident pressure

[b] $P_{r}$ is the reflected pressure

[c] $t_{p}$ is the duration of the positive phase. The reflected pressure duration is based on the clearing times and would be of less magnitude.

Table 8

Tests on windows from ESKIMO III event

| $P_{so}^{a}$ kPa (psi) | $P_{r}^{b}$ kPa (psi) | $t_{p}^{c}$ msec | Glass damage |
|---|---|---|---|
| 4.13 (0.6) | 8.26 (1.2) | 250 | 8 out of 10 panels broke. 8 of the panels were between 5.89 mm (1/4 in ±) and 6.07 mm (1/4 in ±) thick and 1 was 3.18 mm (1/8 ±) thick. |
| 3.44 (0.5) | 6.88 (1.0) | 260 | 7 out of 8 panels broke. 5 of the panels were between 5.89 mm (1/4 in ±) and 6.07 mm (1/4 in ±) thick and 3 were 3.18 mm (1/8 in ±) thick. |
| 2.06 (0.3) | 4.13 (0.6) | 290 | 3 of the 8 panels broke. [One 5.89 mm (1/4 in ±) and two 3.18 mm (1/8 in ±) thick.] |

a $P_{so}$ is the incident pressure

b $P_r$ is the reflected pressure

c $t_p$ is the duration of the positive phase. The reflected pressure duration is based on the clearing times and would be of less magnitude.

## Table 9

Recommended design criteria for maximum blast pressure capacity for glass mounted in rigid window frames

| Glass | Peak incident or reflected pressure - kPa (psi) | | | | |
|---|---|---|---|---|---|
| | Triangular load duration - msec | | | | |
| | < 10 | 10 - 20 | 21 - 40 | 41 - 100 | > 100 |
| Tempered glass 3.18 mm (1/8 in) | 21.0 (3.0) | 17.0 (2.5) | 14.0 (2.0) | 10.0 (1.5) | 6.9 (1.0) |
| Tempered glass 6.35 mm (1/4 in) | 41.0 (6.0) | 31.0 (4.5) | 28.0 (4.0) | 21.0 (3.0) | 17.0 (2.5) |
| Tempered glass 9.52 mm (3/8 in) | 55.0 (8.0) | 48.0 (7.0) | 41.0 (6.0) | 34.0 (5.0) | 28.0 (4.0) |
| Regular glass 3.18 mm (1/8 in) | 2.8 (0.4) | 2.1 (0.3) | 1.7 (0.25) | 1.0 (0.15) | 0.7 (0.1) |
| Regular glass 6.35 mm (1/4 in) | 4.8 (0.7) | 4.1 (0.6) | 3.4 (0.5) | 2.8 (0.4) | 2.1 (0.3) |
| Regular glass 9.52 mm (3/8 in) | 6.2 (0.9) | 5.5 (0.8) | 4.8 (0.7) | 4.1 (0.6) | 3.4 (0.5) |

<u>Notes</u>:

1. See Table 10 for limiting blast capacities where glass is mounted in aluminum window frames.
2. Rigid window frame provides continuous support of glass similar to that provided by wooden frames used in the tests (Figs 2 and 20).
3. Blast capacities are applicable to glass area of 1.86 sq m (20 sq ft) or less.
4. Tempered glass shall meet the requirements of ANSI Z97.1.
5. Blast capacities for the various load durations were extrapolated from test results based on relative dynamic load factors.
6. Blast capacities for 3.18-mm (1/8-in) thick glass were extrapolated from test results based on relative strength under wind loading (Figs 39 and 40) and relative dynamic load factors.

Table 10

Recommended design criteria for maximum blast pressure capacity for glass mounted in aluminum window frames of the type tested

| Aluminum frame window | Peak incident or reflected pressure - kPa (psi) Triangular load duration - msec < 10 | 10 - 20 | 21 - 40 | 41 - 100 | > 100 |
|---|---|---|---|---|---|
| Unmodified | 10.0 (1.5) | 7.6 (1.1) | 6.9 (1.0) | 6.2 (0.9) | 5.5 (0.8) |
| Strengthened per Figure 22 | 21.0 (3.0) | 15.0 (2.2) | 14.0 (2.0) | 12.0 (1.8) | 11.0 (1.6) |

Notes:

1. Blast capacities are applicable to glass area of 1.86 sq m (20 sq ft) or less.
2. Blast capacities for the various load durations were extrapolated from test results based on relative dynamic load factors.

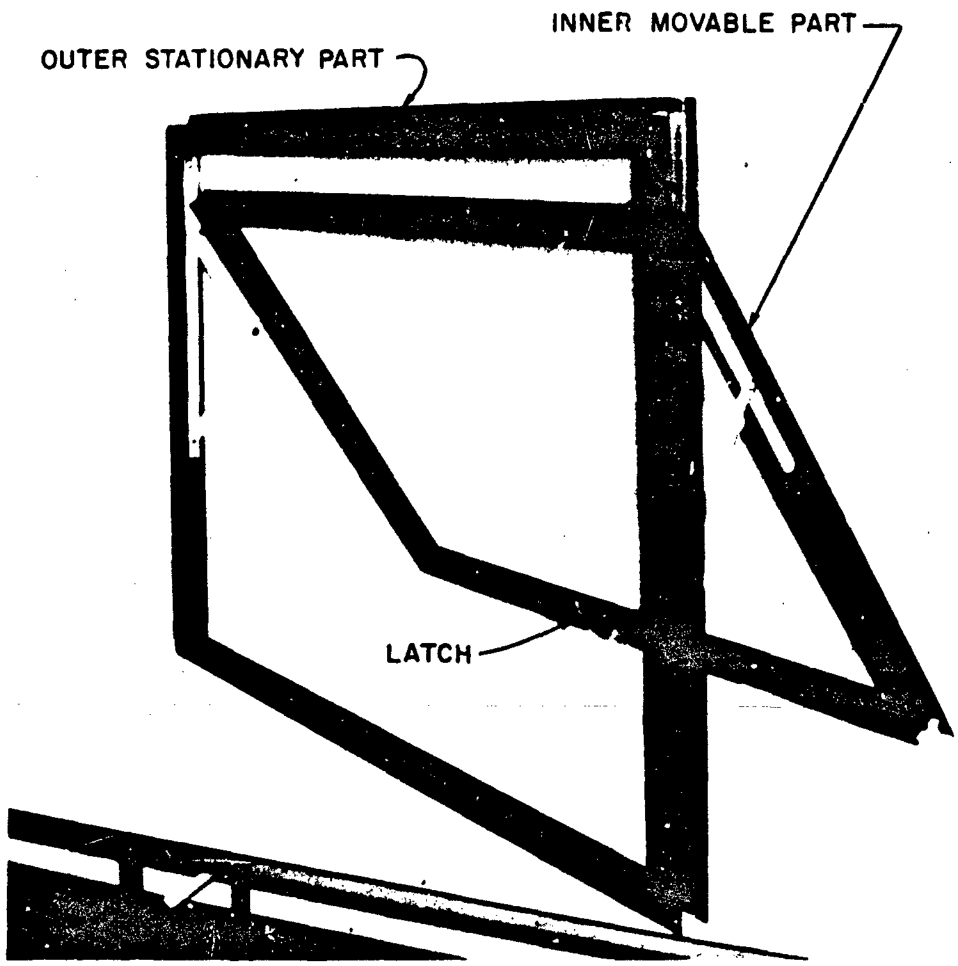



**Fig 1 Aluminum window frame**

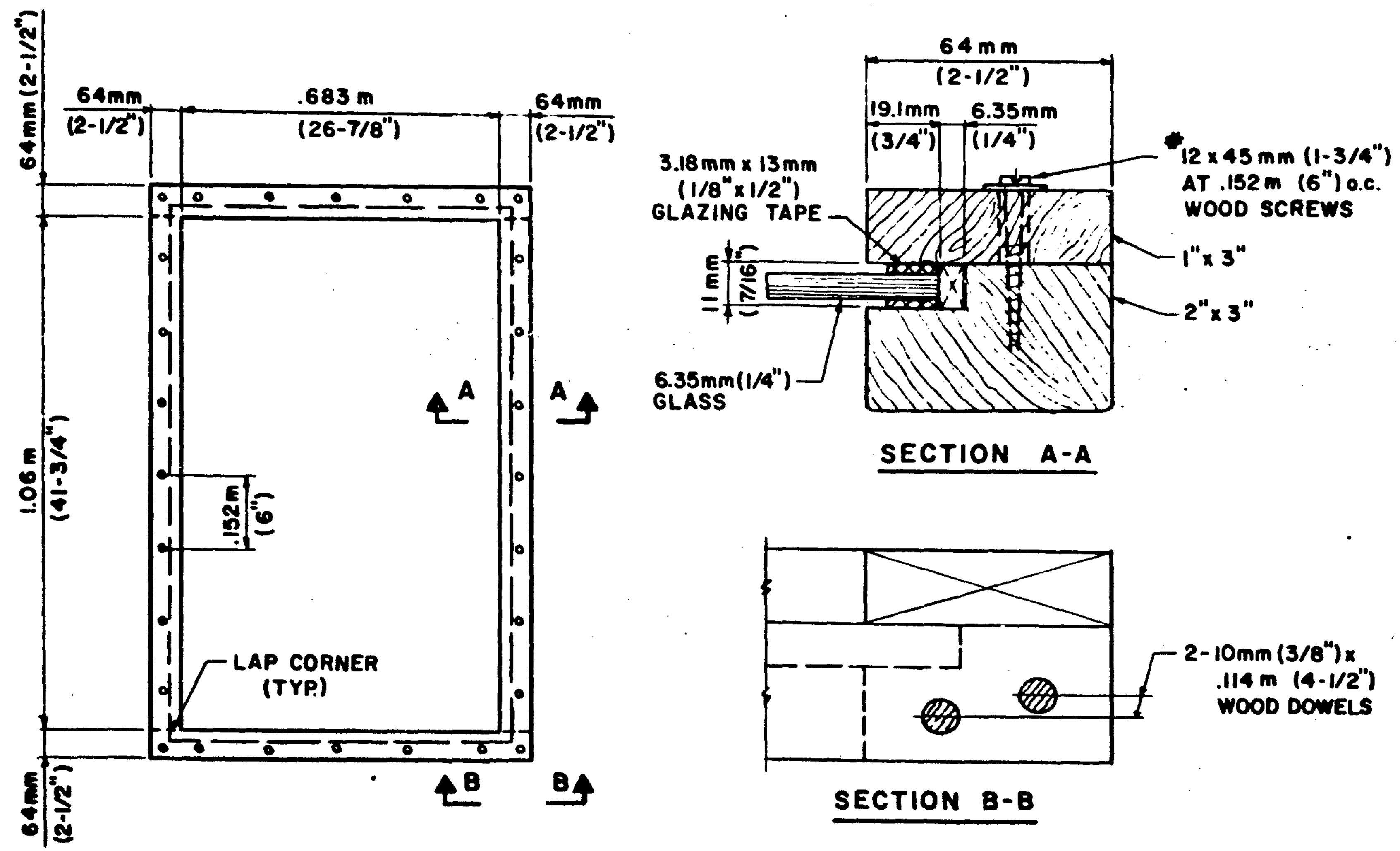



Fig 2 Plan and details of wooden frame for static tests

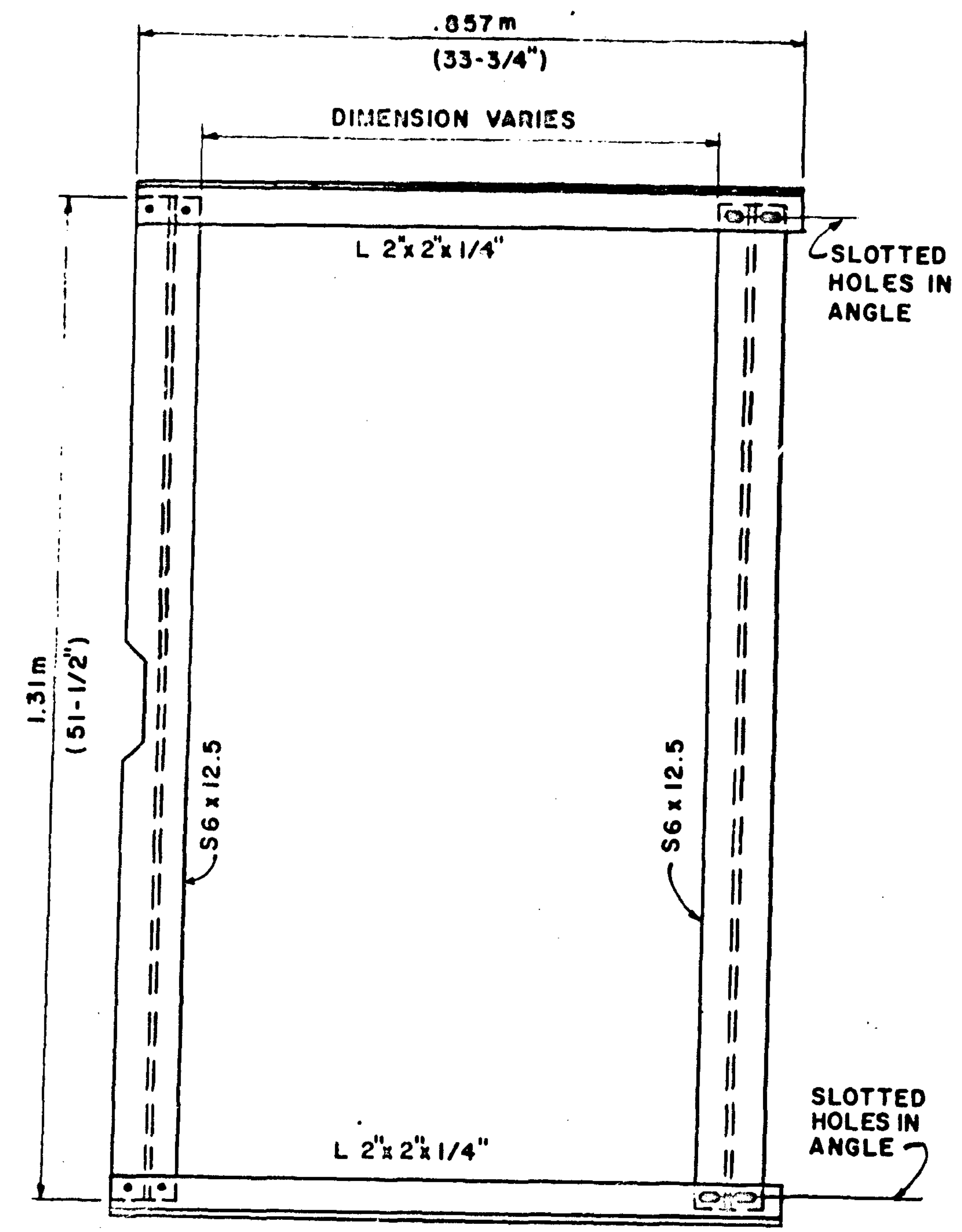



Fig 3 Steel support framework - plan view

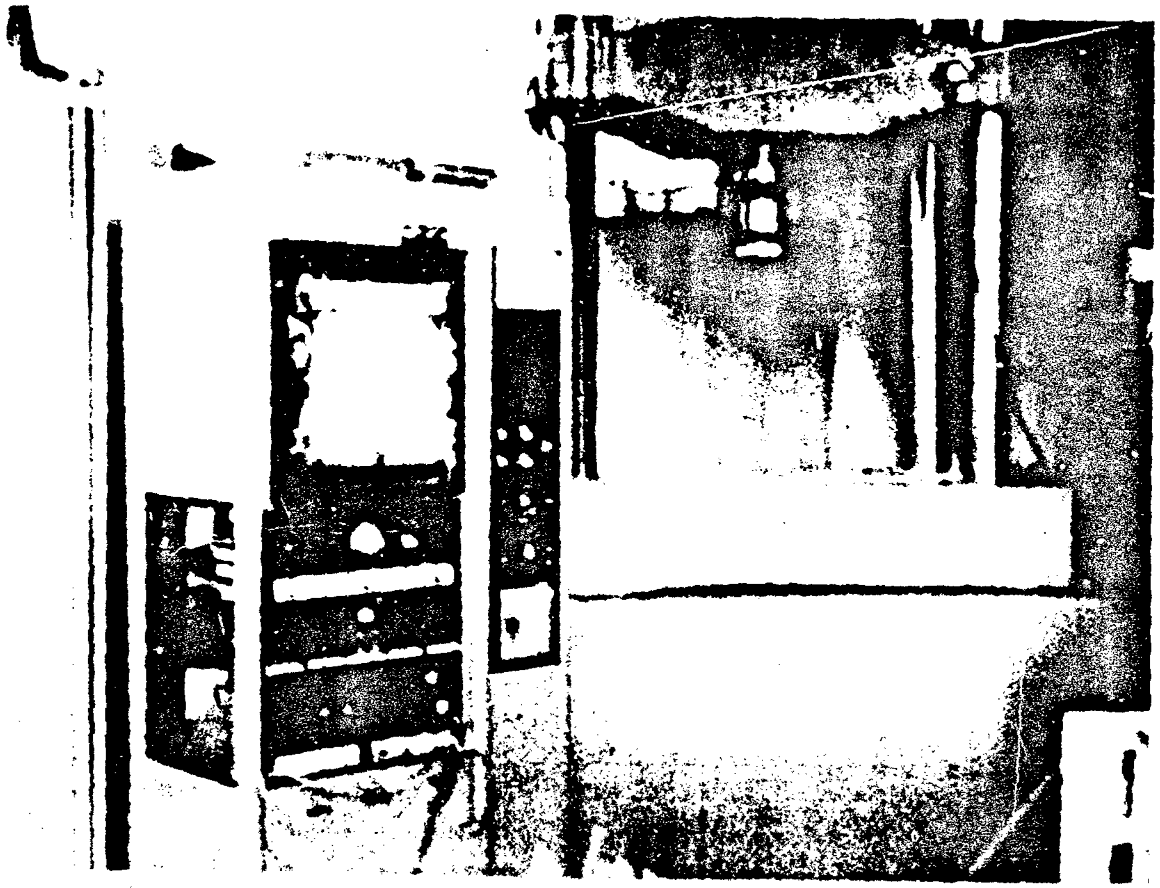


Fig 4 Instron testing machine

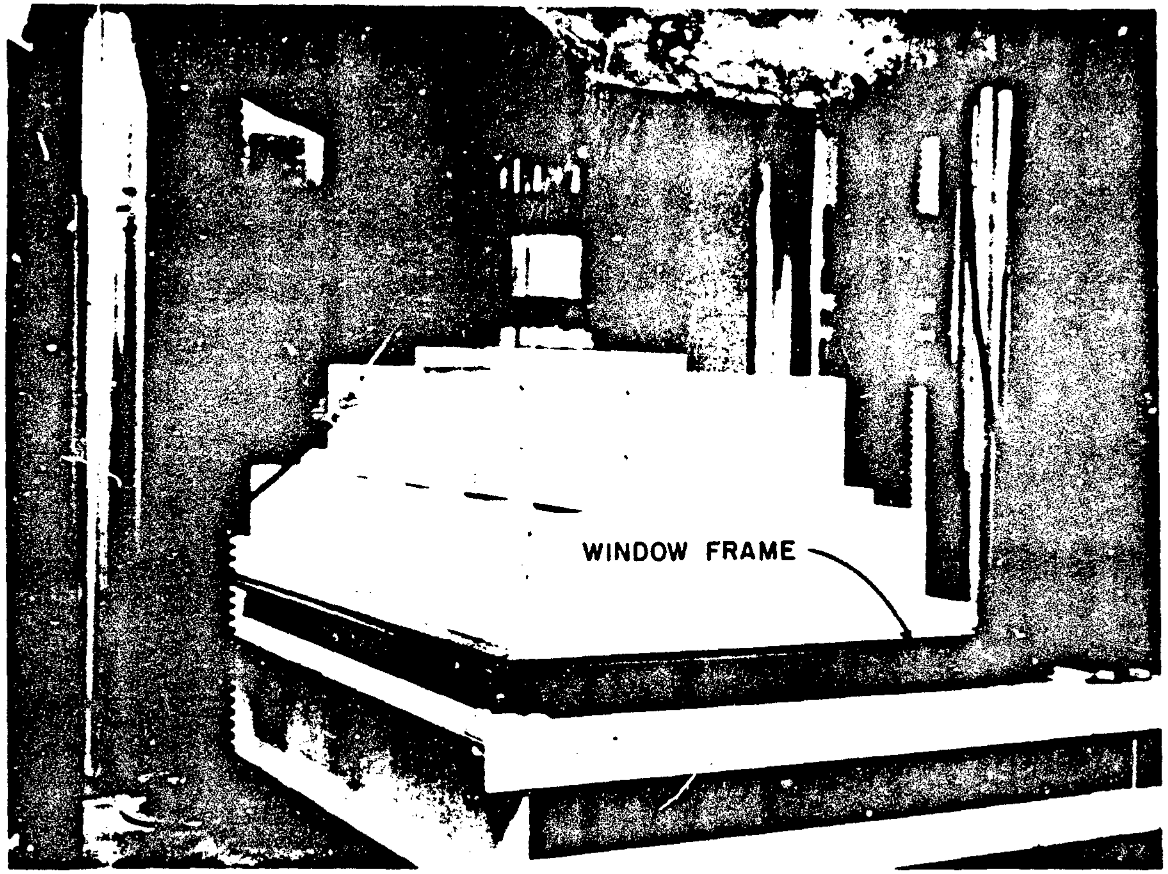



Fig 5 Test setup for testing aluminum window frame

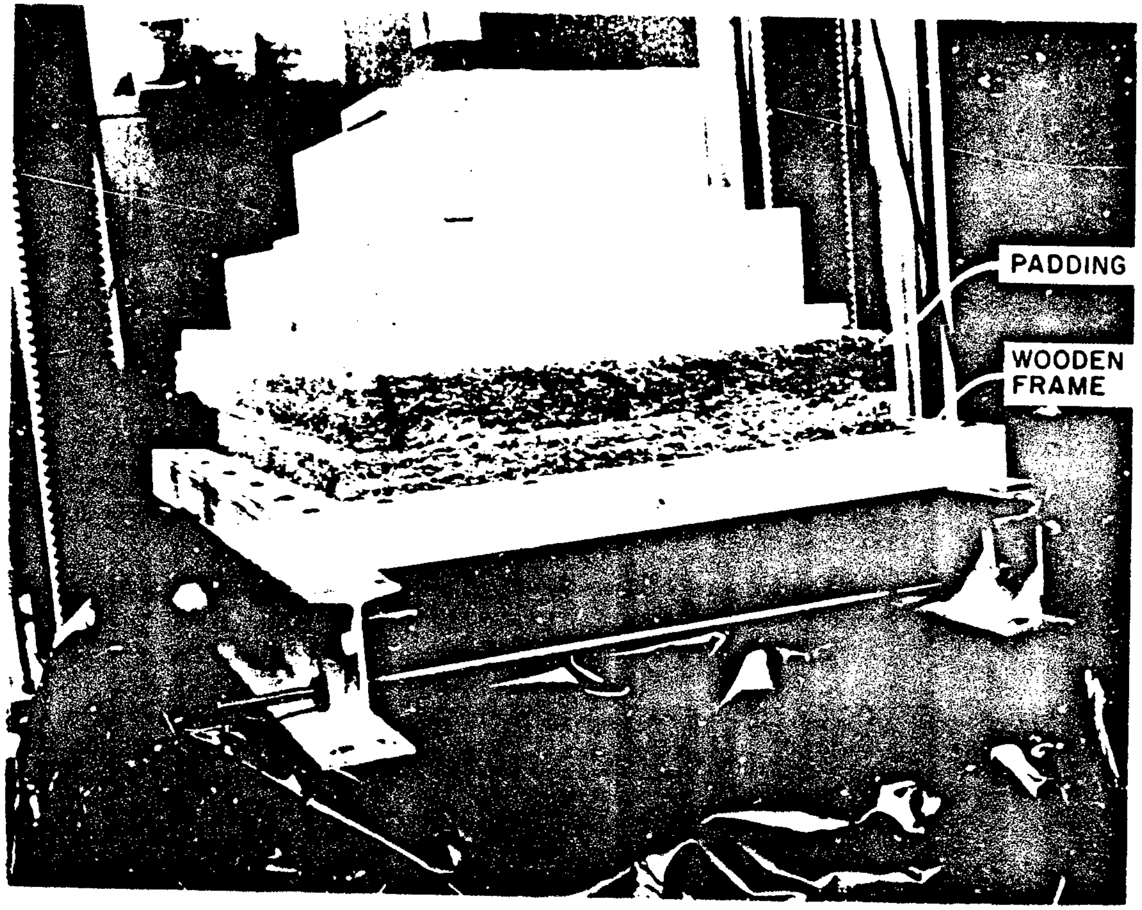



Fig 6 Test setup for testing glass in wooden frame

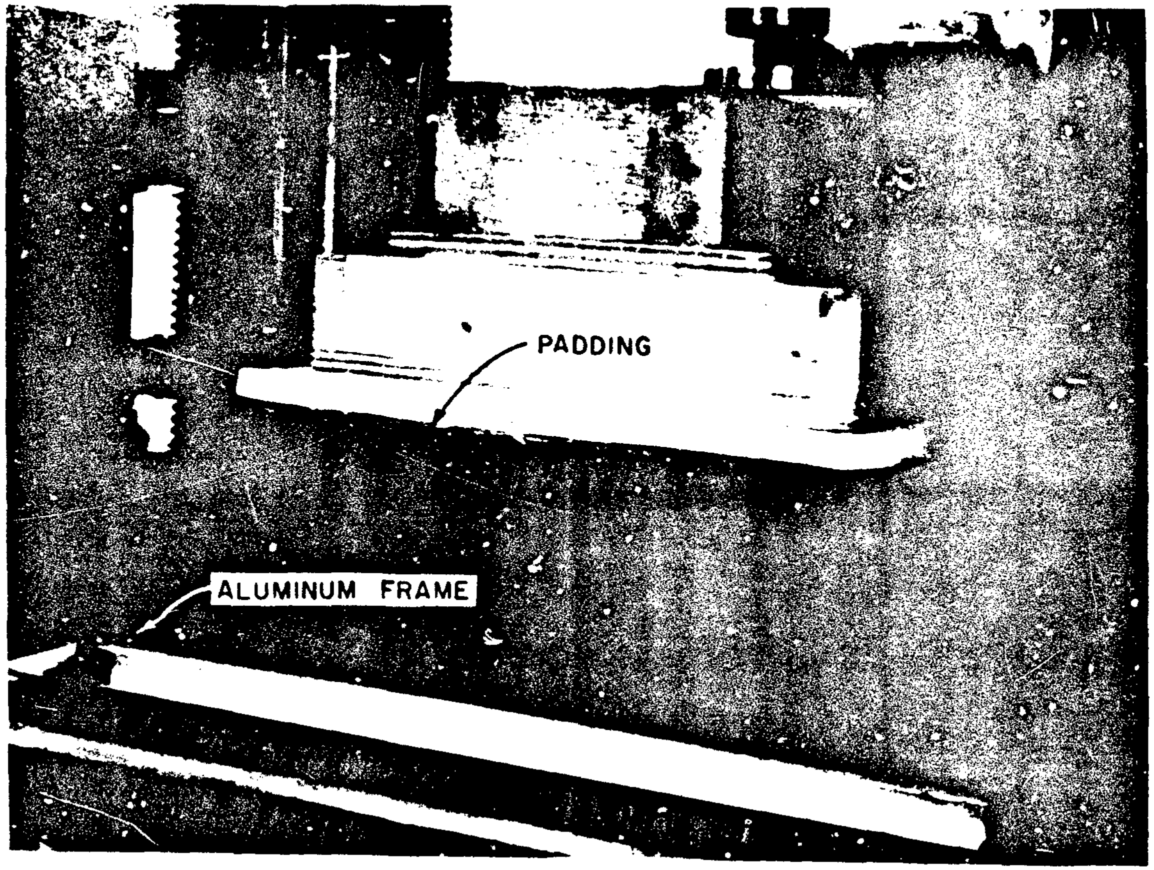



Fig 7 Test setup for testing glass in aluminum window frame

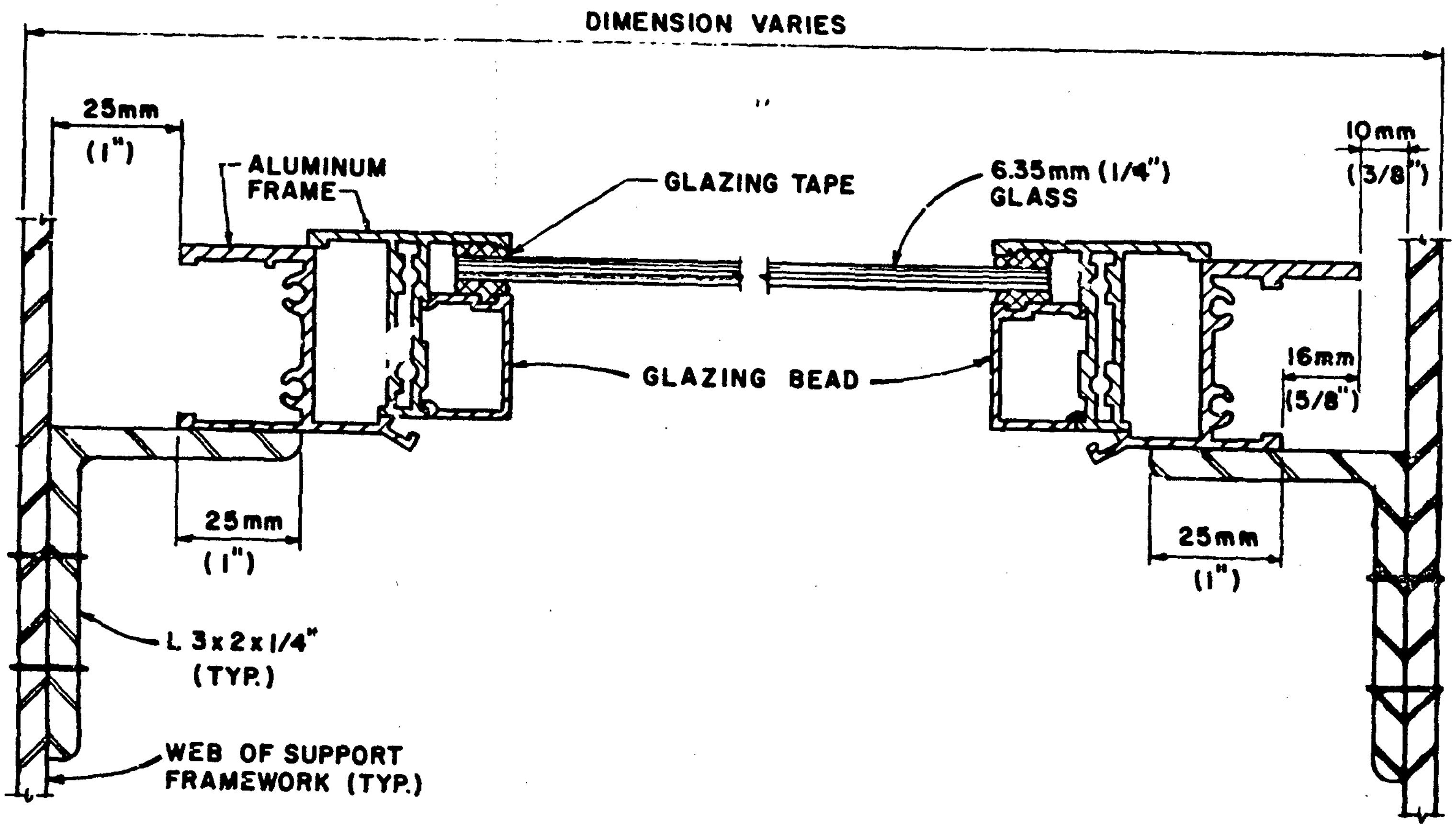



Fig 8 Cross-section of aluminum window frame with glass test setup

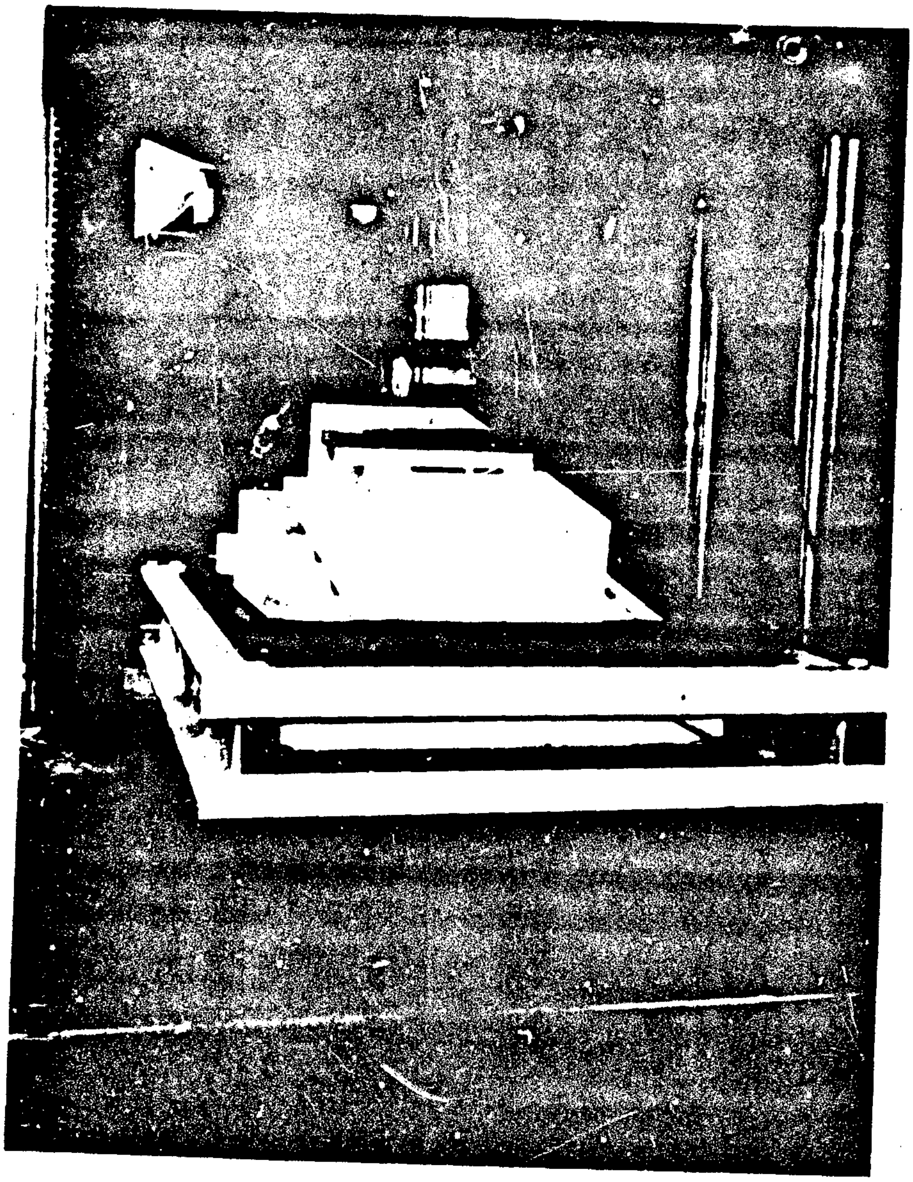


Fig 9 Failure of aluminum window frame

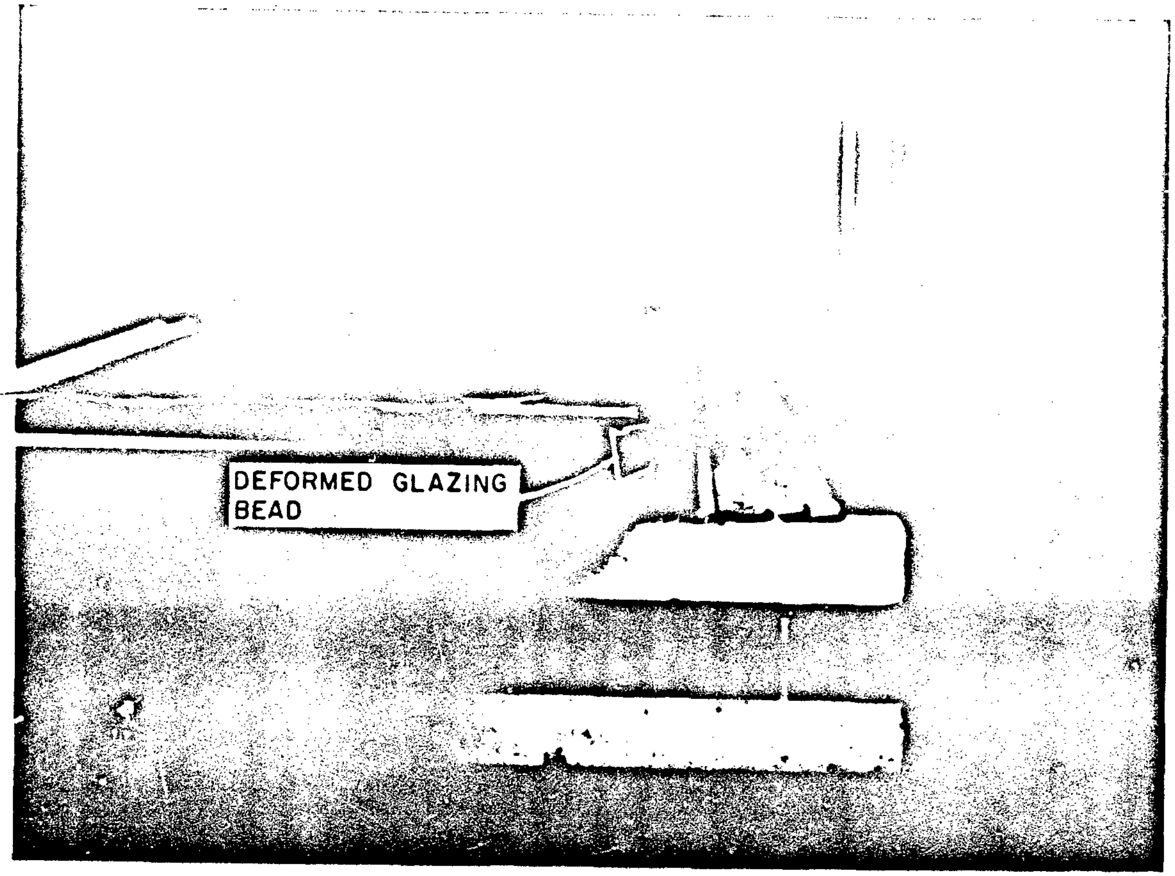



Fig 10  Deformed aluminum glazing bead

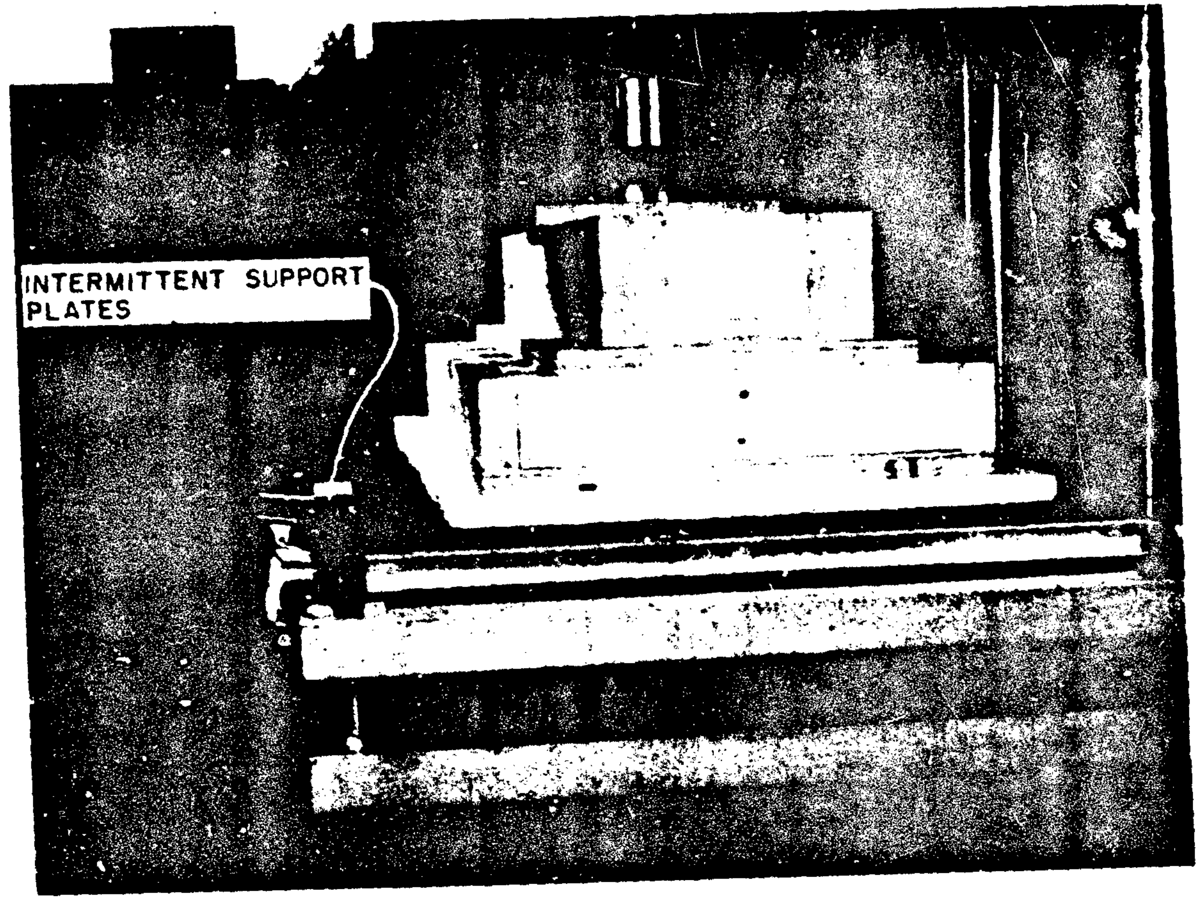



Fig 11 Test setup with intermittent supports

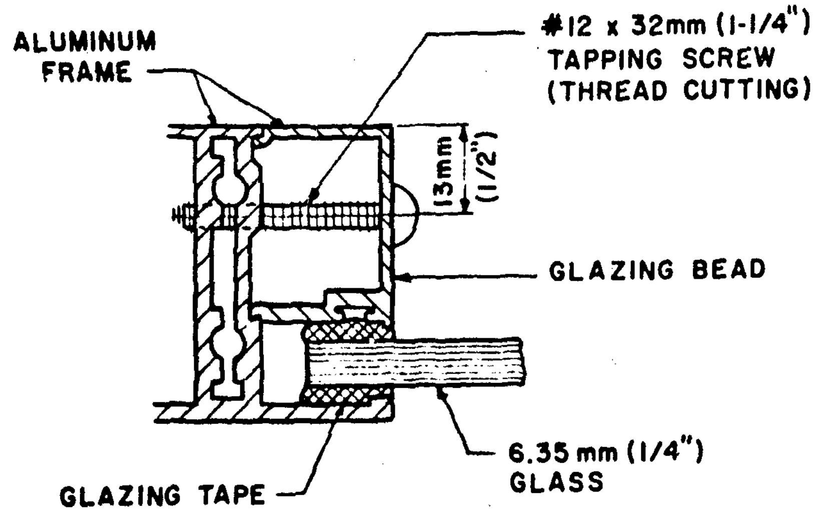



Fig 12 Cross-section of aluminum glazing bead strengthened with screws


**Fig 13 Window latch before test**

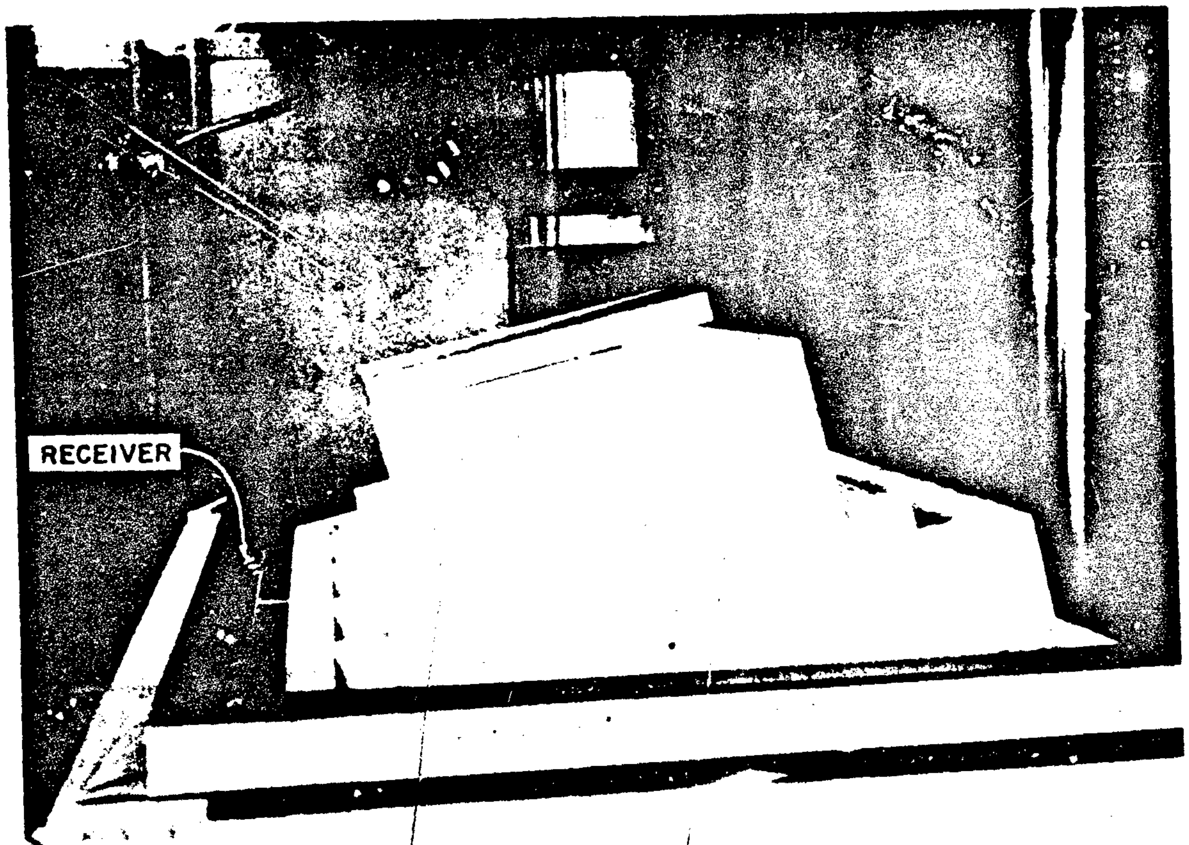



Fig 14 Window latch failure

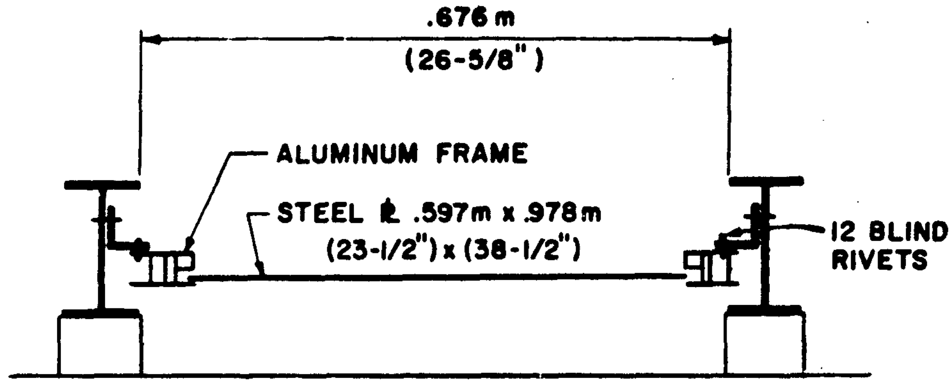



Fig 15 Test setup for reverse loading on aluminum window frame

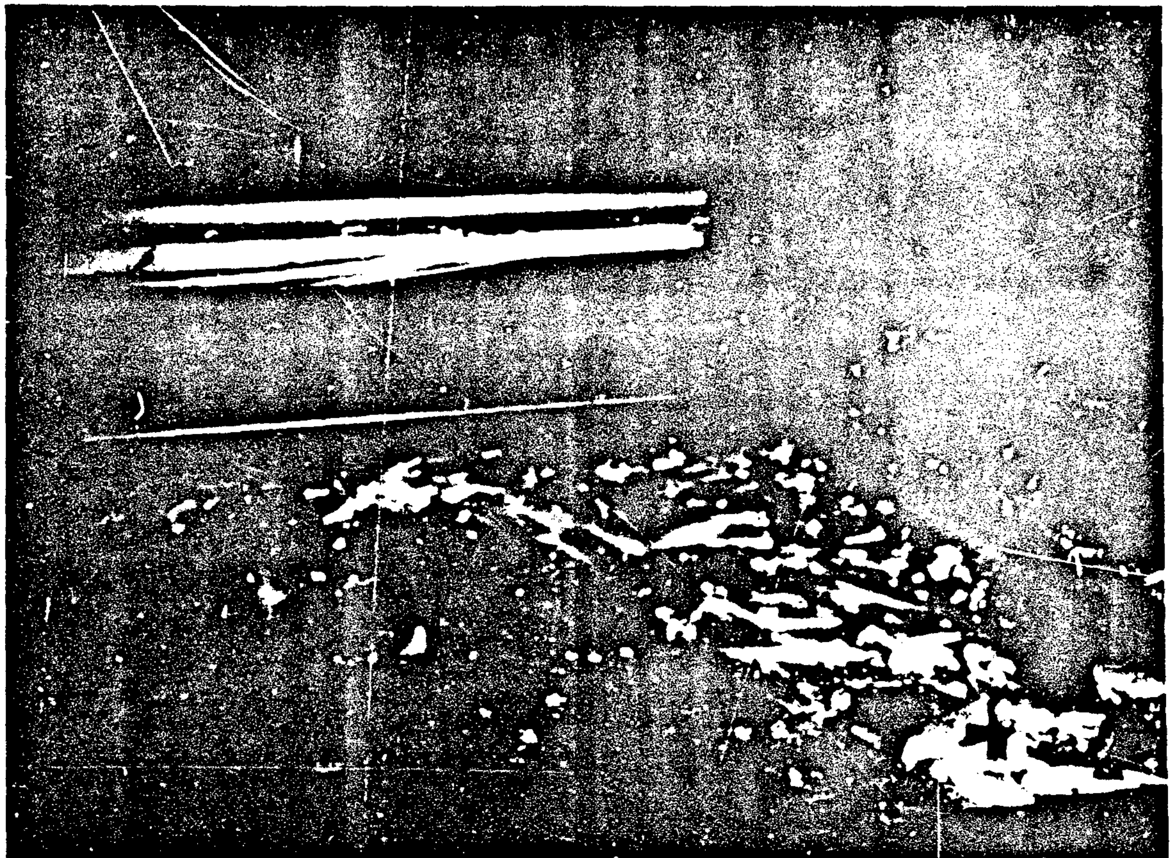


Fig 16 Tempered glass breakage and wooden frame damage

Fig 17  Regular glass breakage

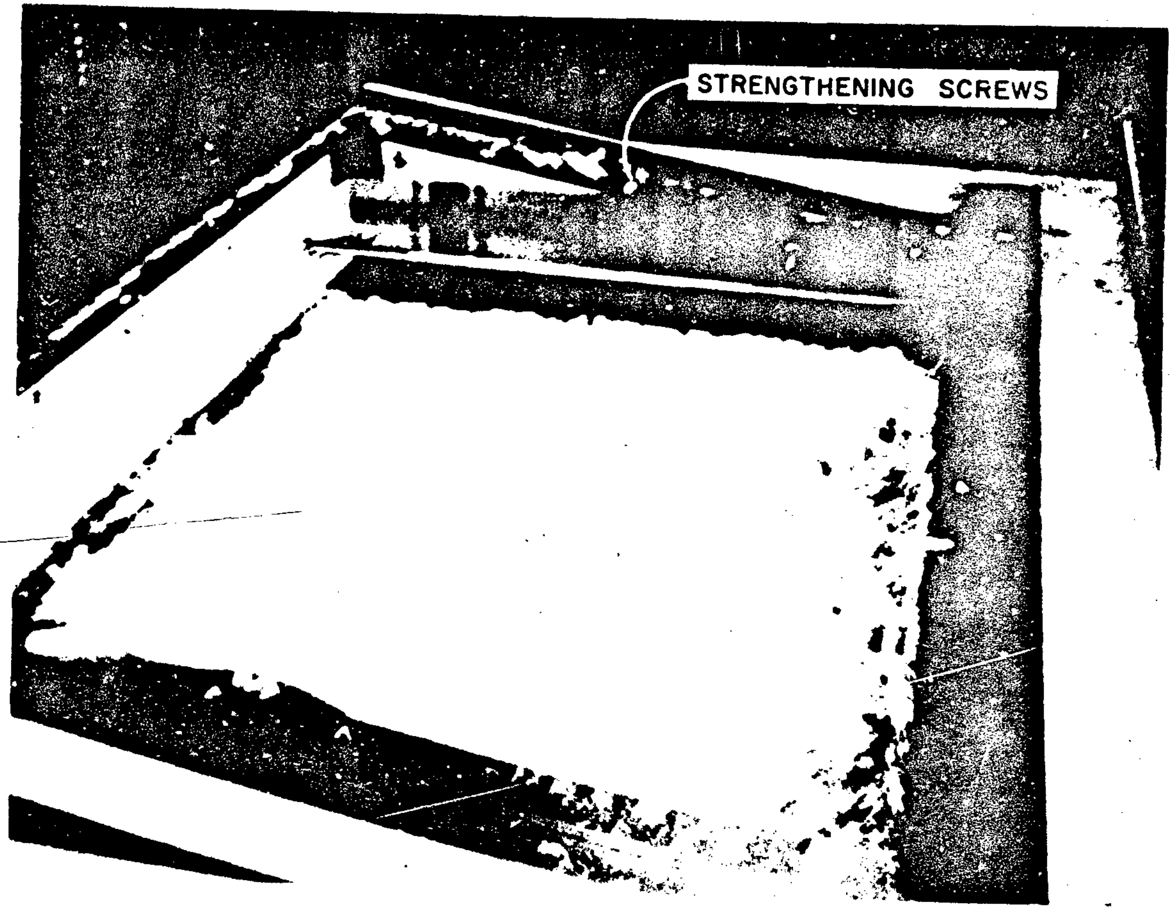



Fig 18  Tempered glass breakage in strengthened aluminum window frame

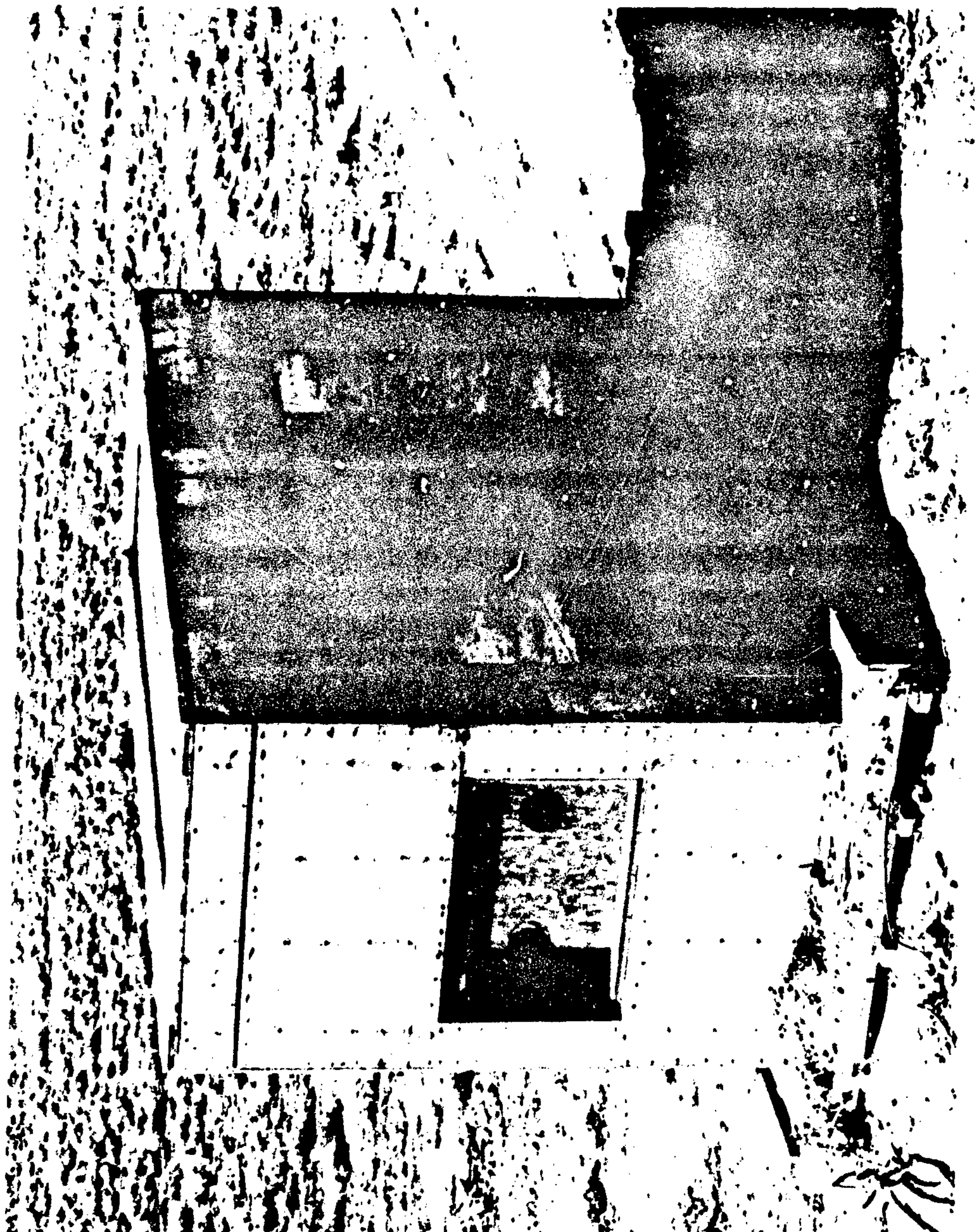


Fig 19 Test Structure A

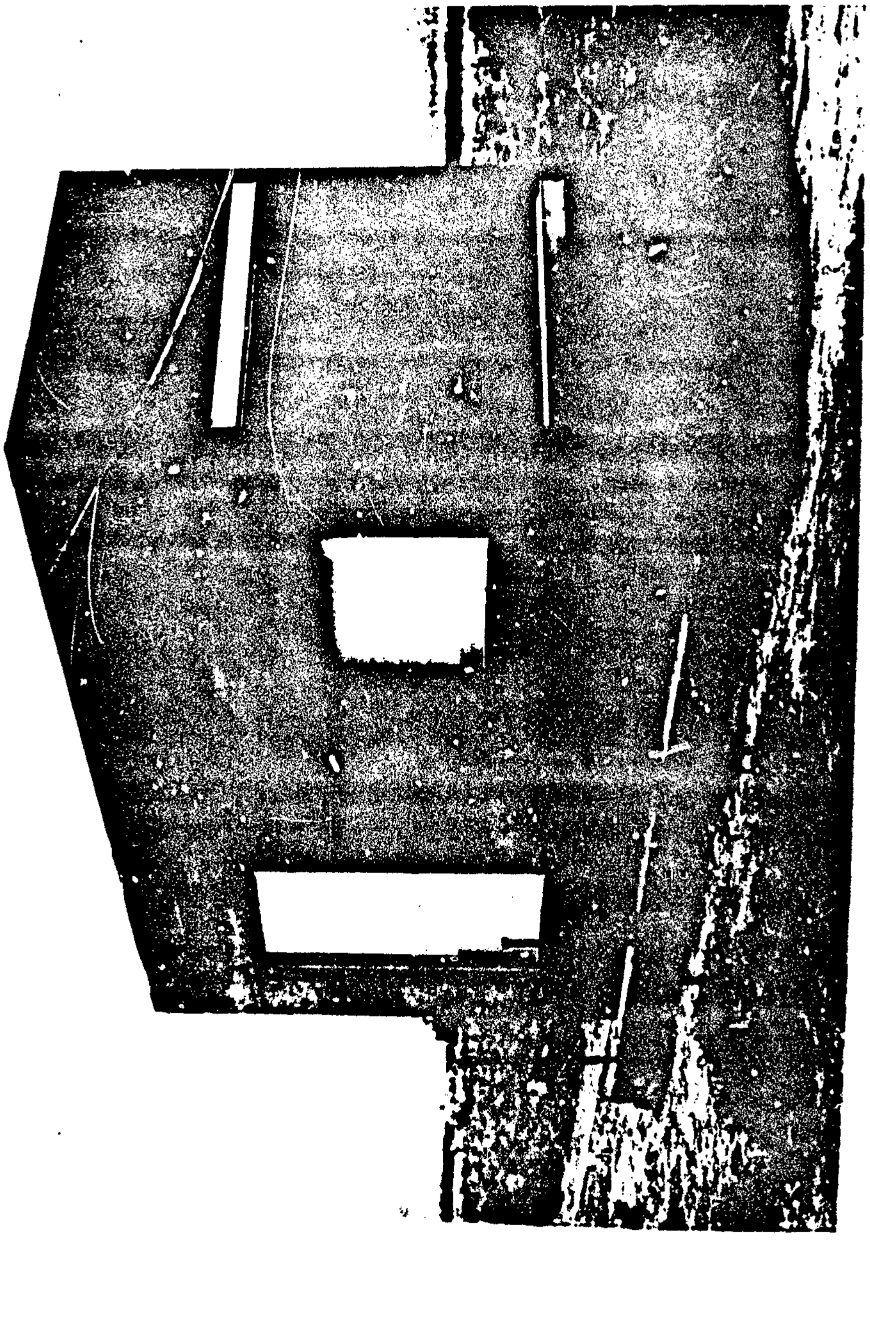


Fig 20 Test Structure B

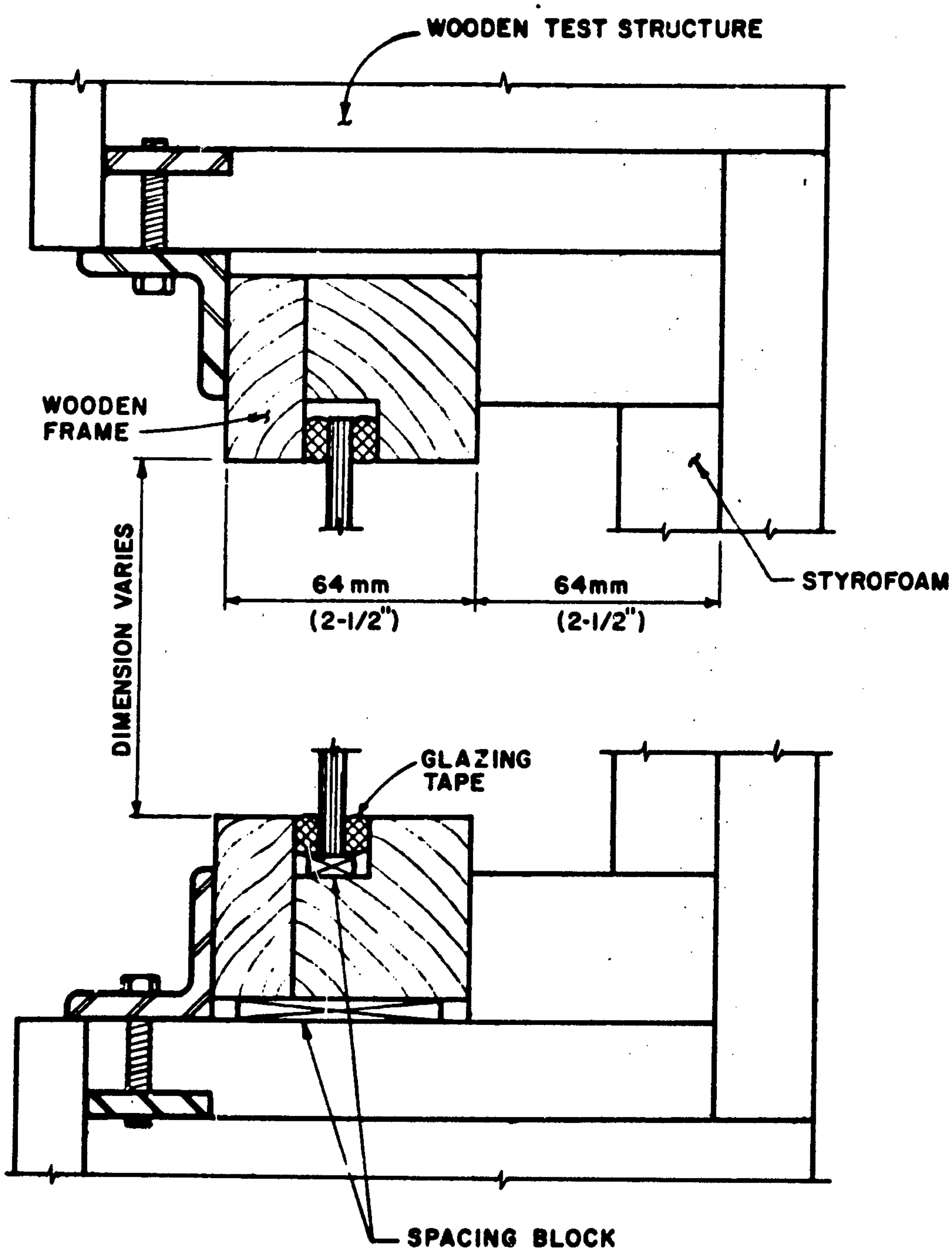



Fig 21 Cross-section of wooden frame mounted in test structure

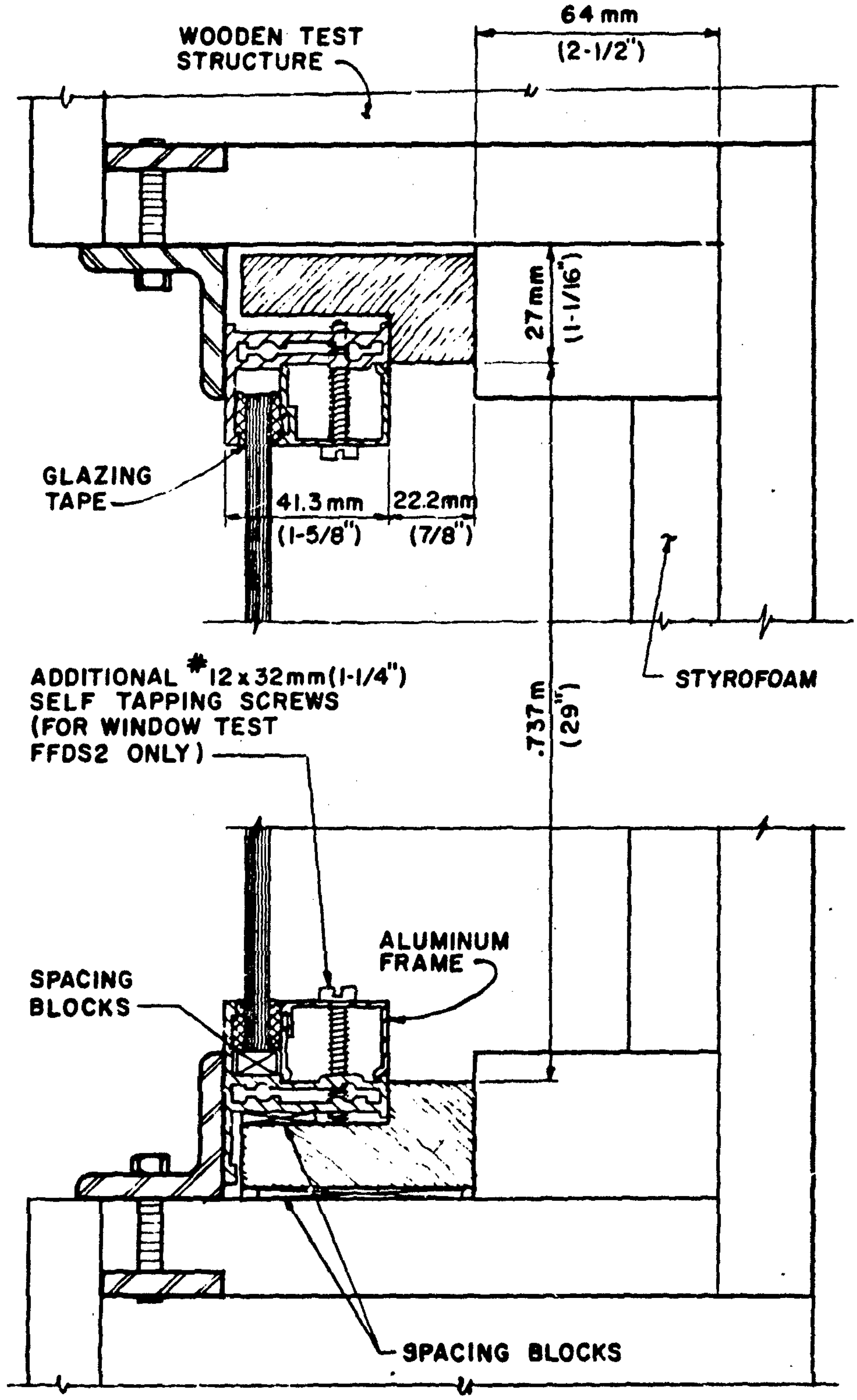



Fig 22 Cross-section of aluminum window frame mounted in test structure

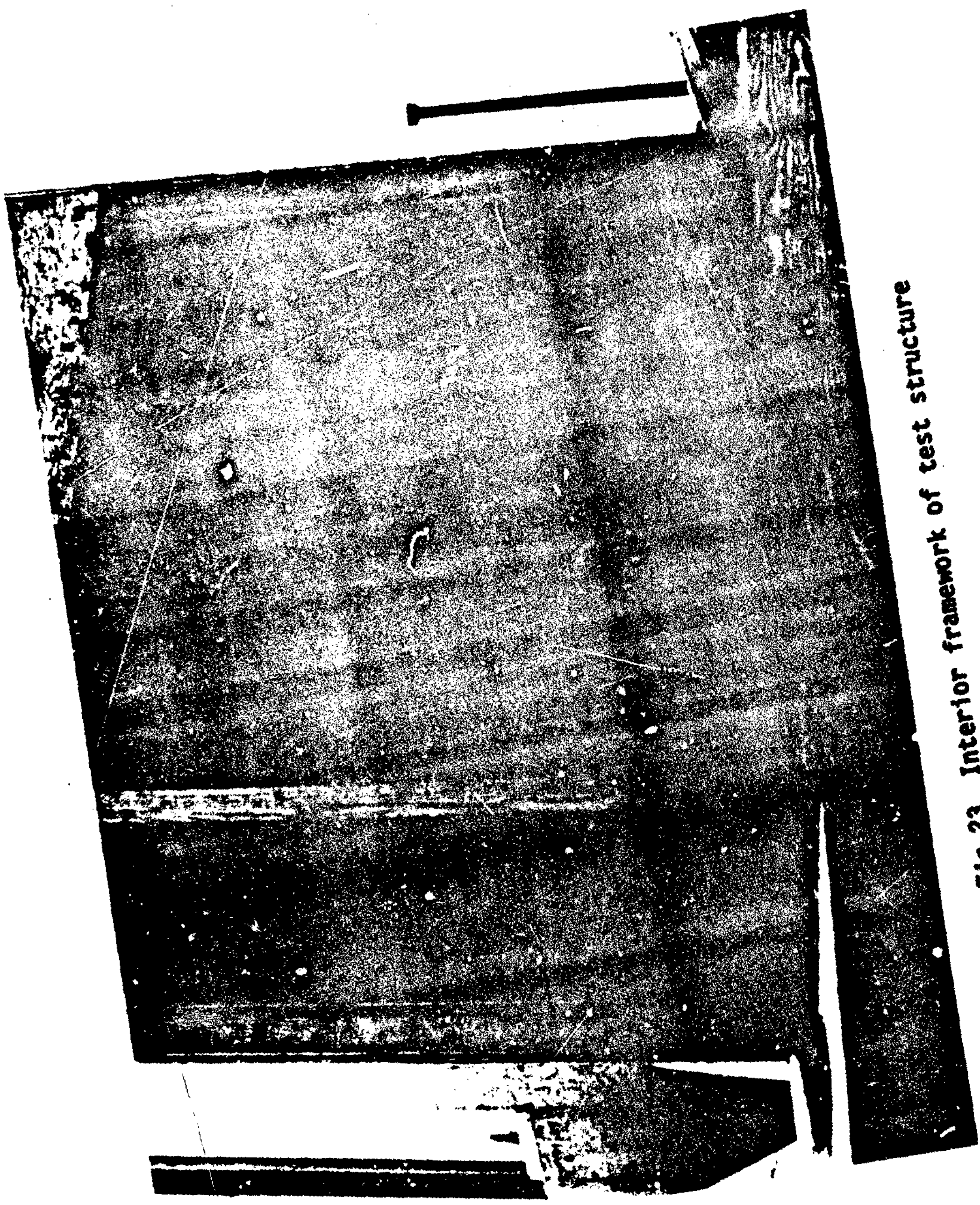


Fig 23 Interior framework of test structure

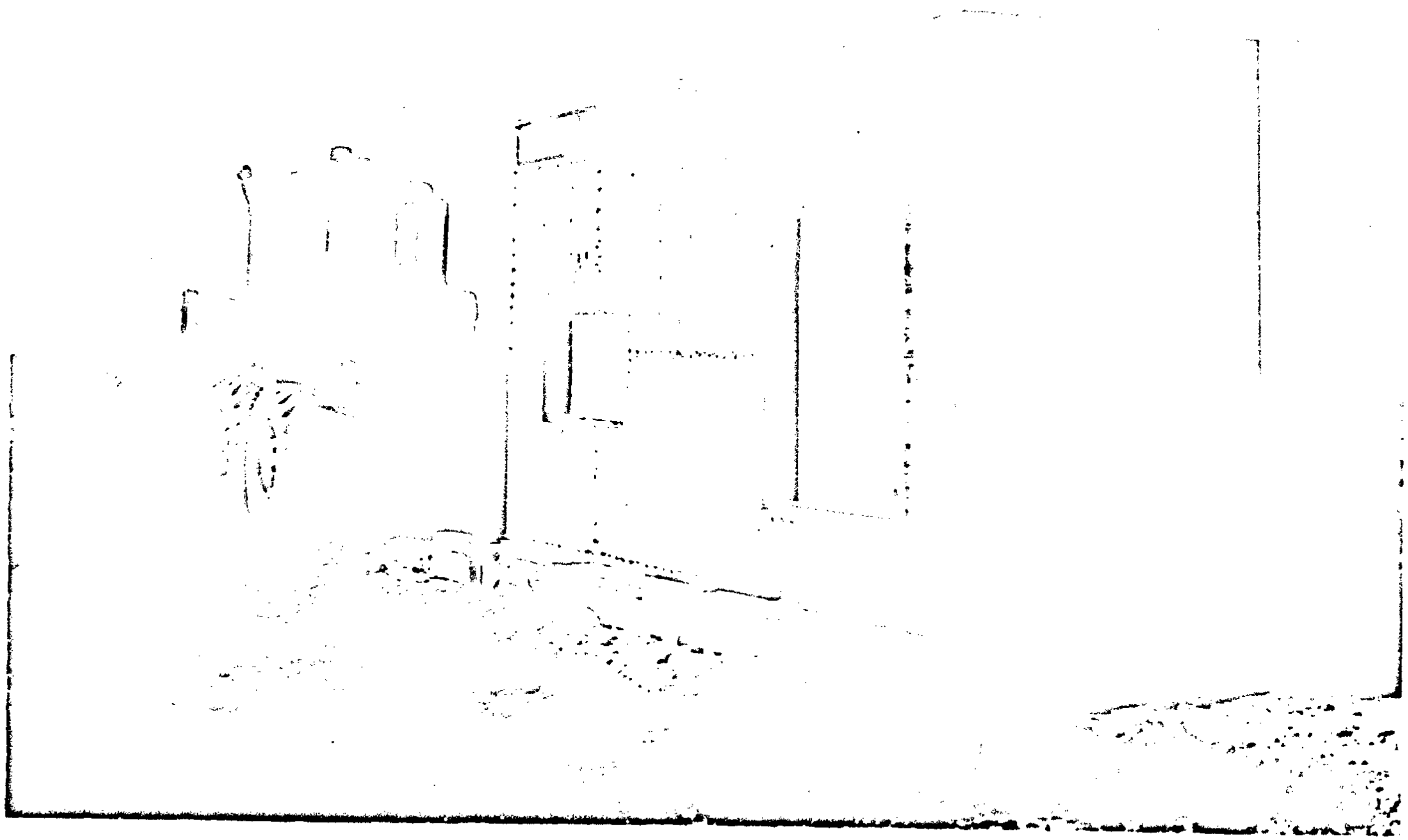


Fig 24  Structure A being pulled to the test site

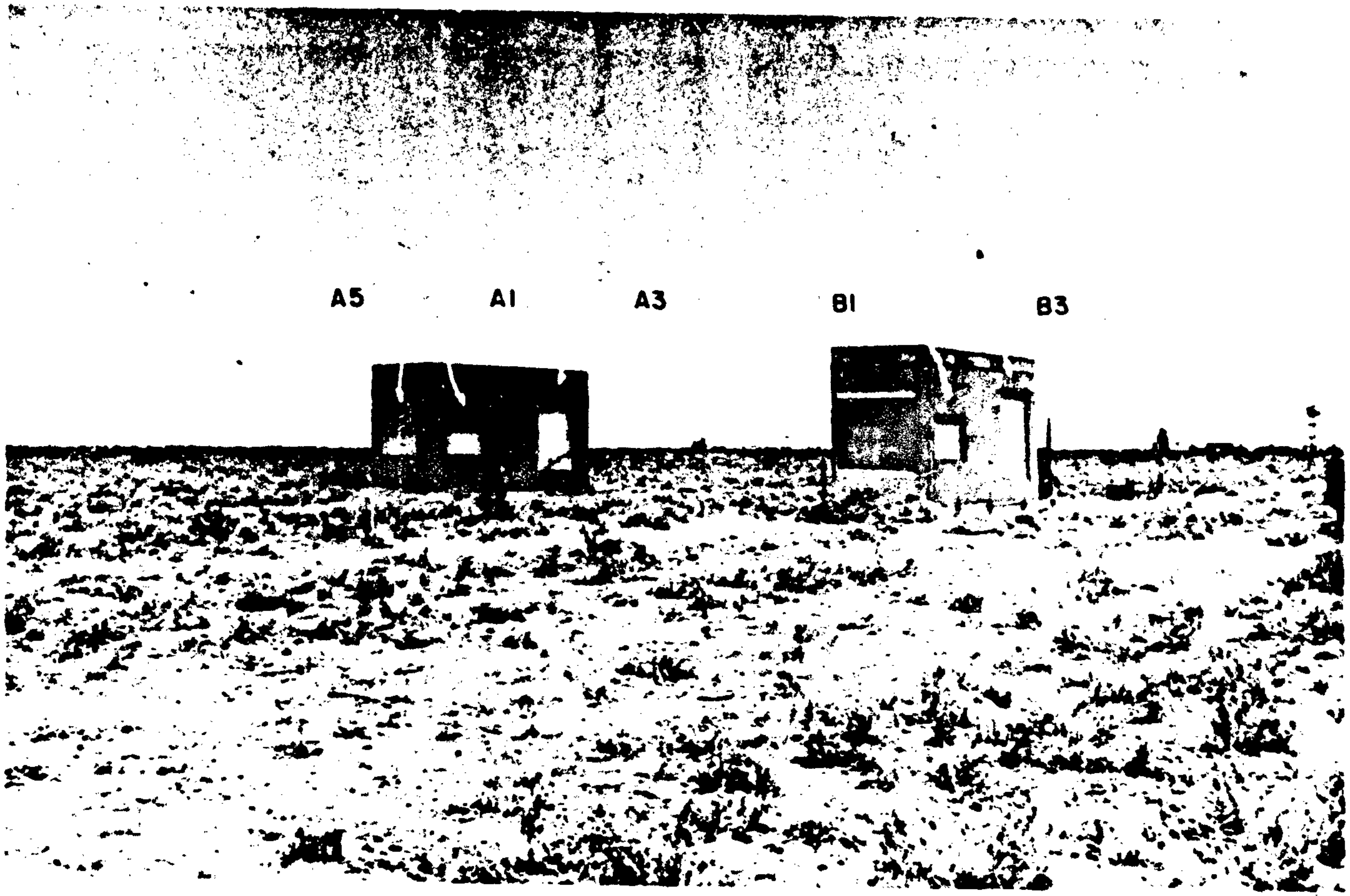



Fig 25 Identification of window openings in test structures

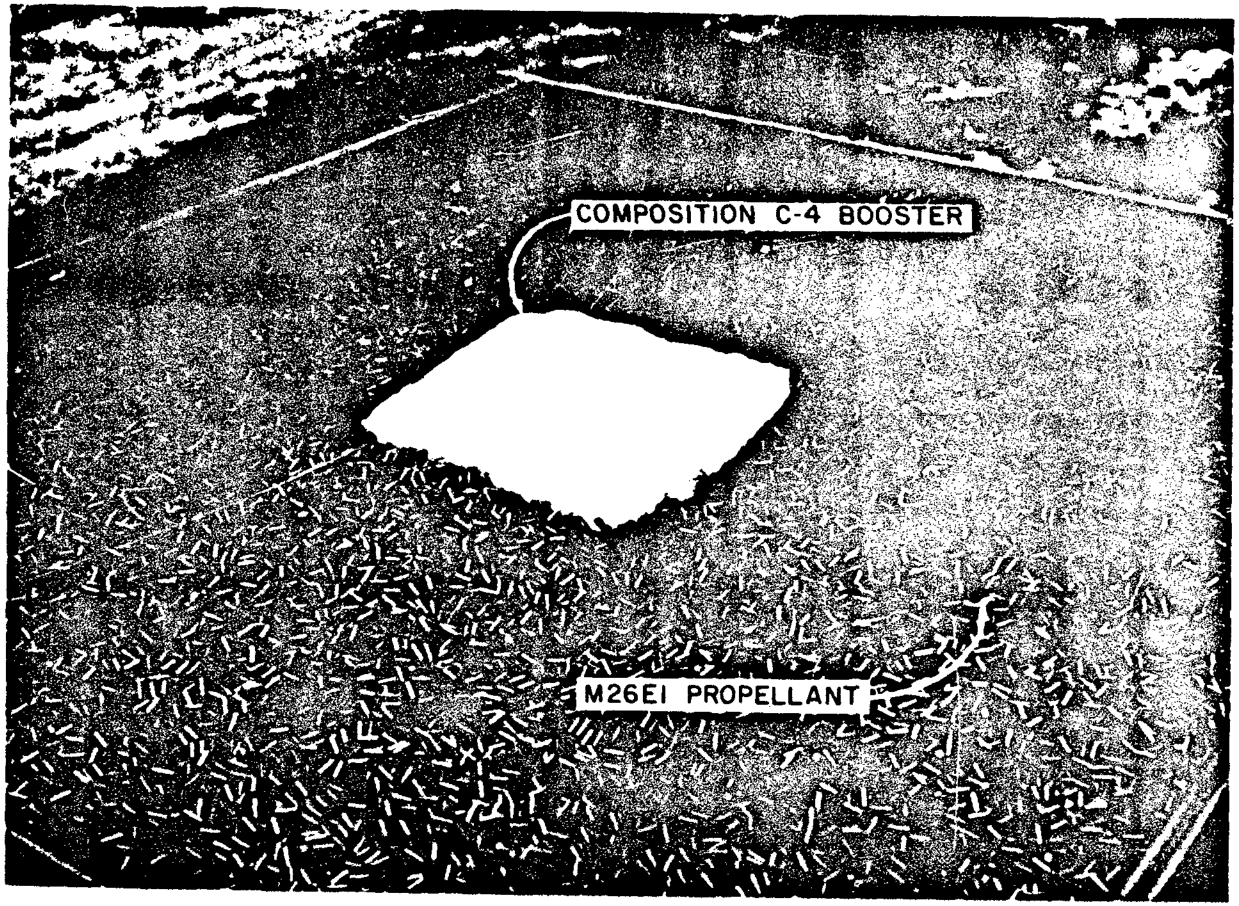



Fig 26 Explosive charge

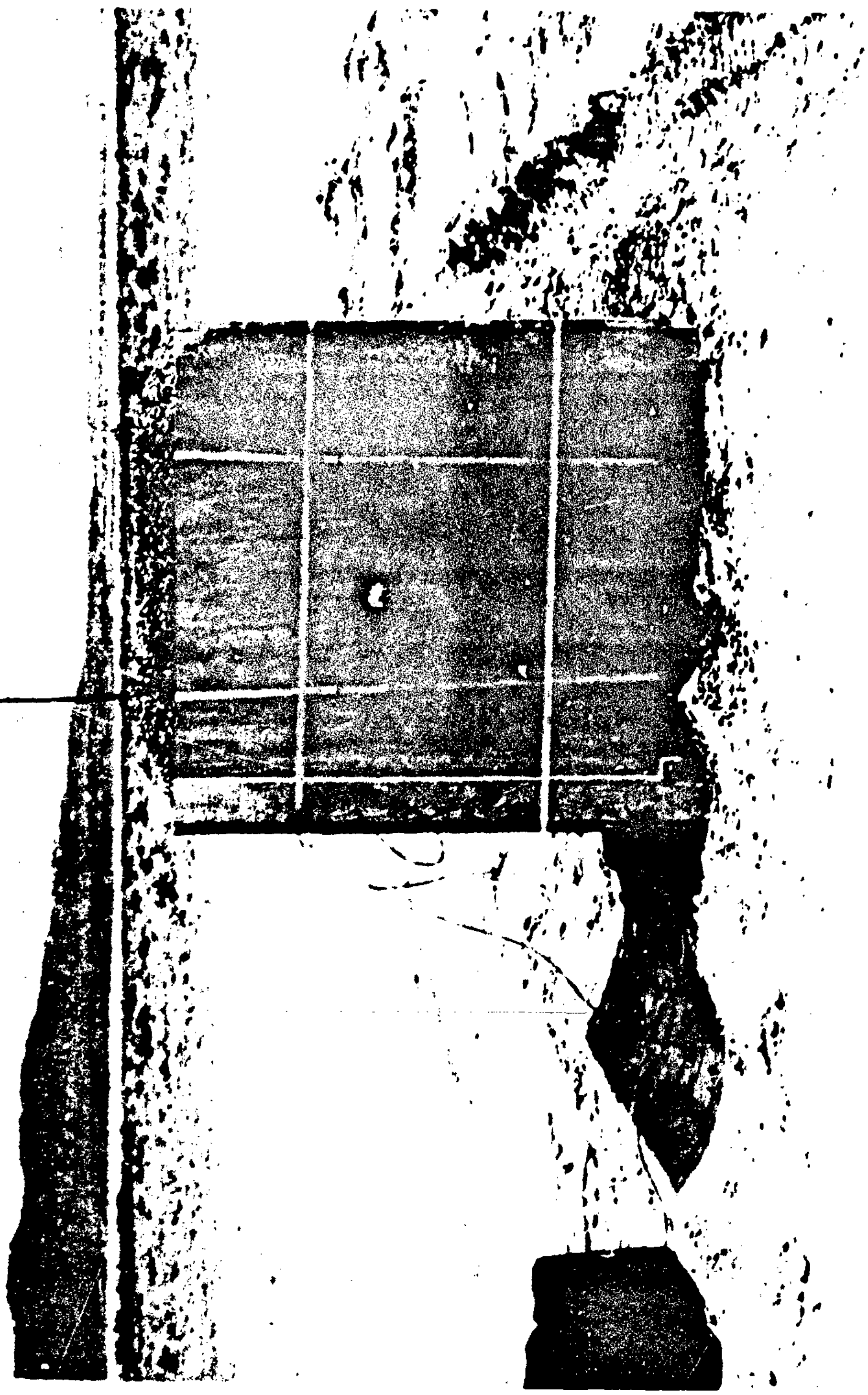


Fig 27 Explosive charge in plywood container

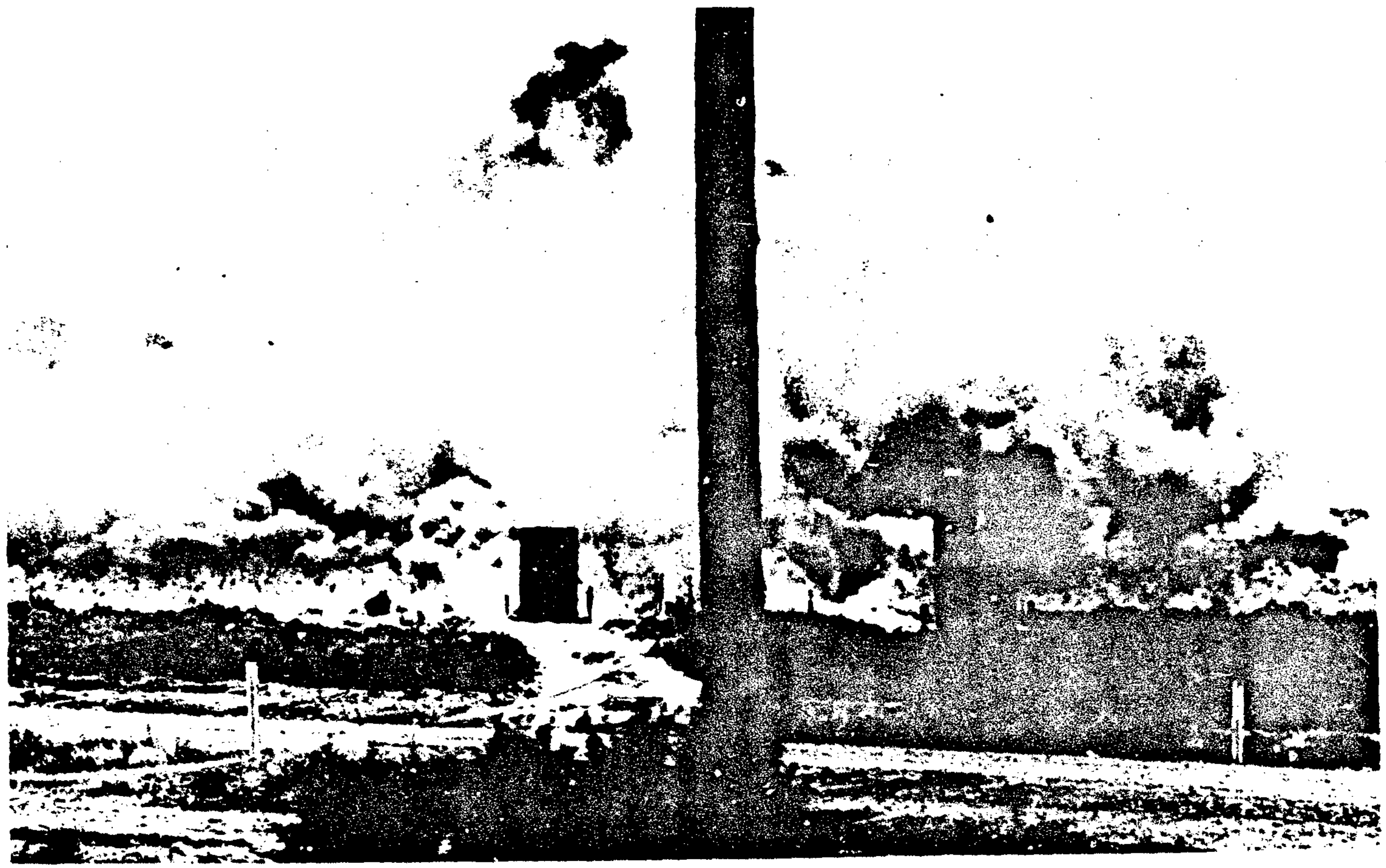


Fig 28 Detonation


Fig 29 Pressure gages mounted on pipes along blast line

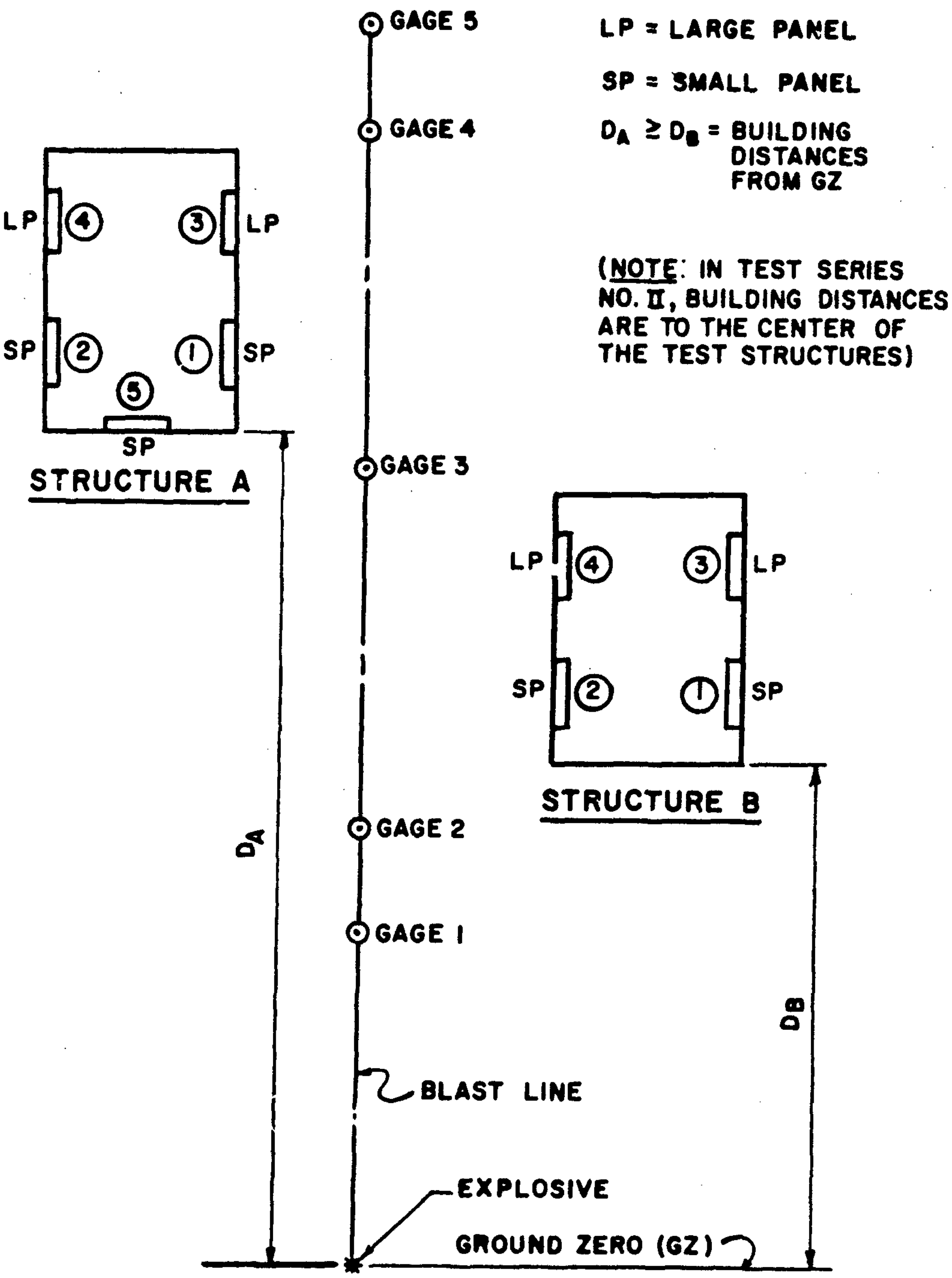



Fig 30 Layout of test structures and pressure gages

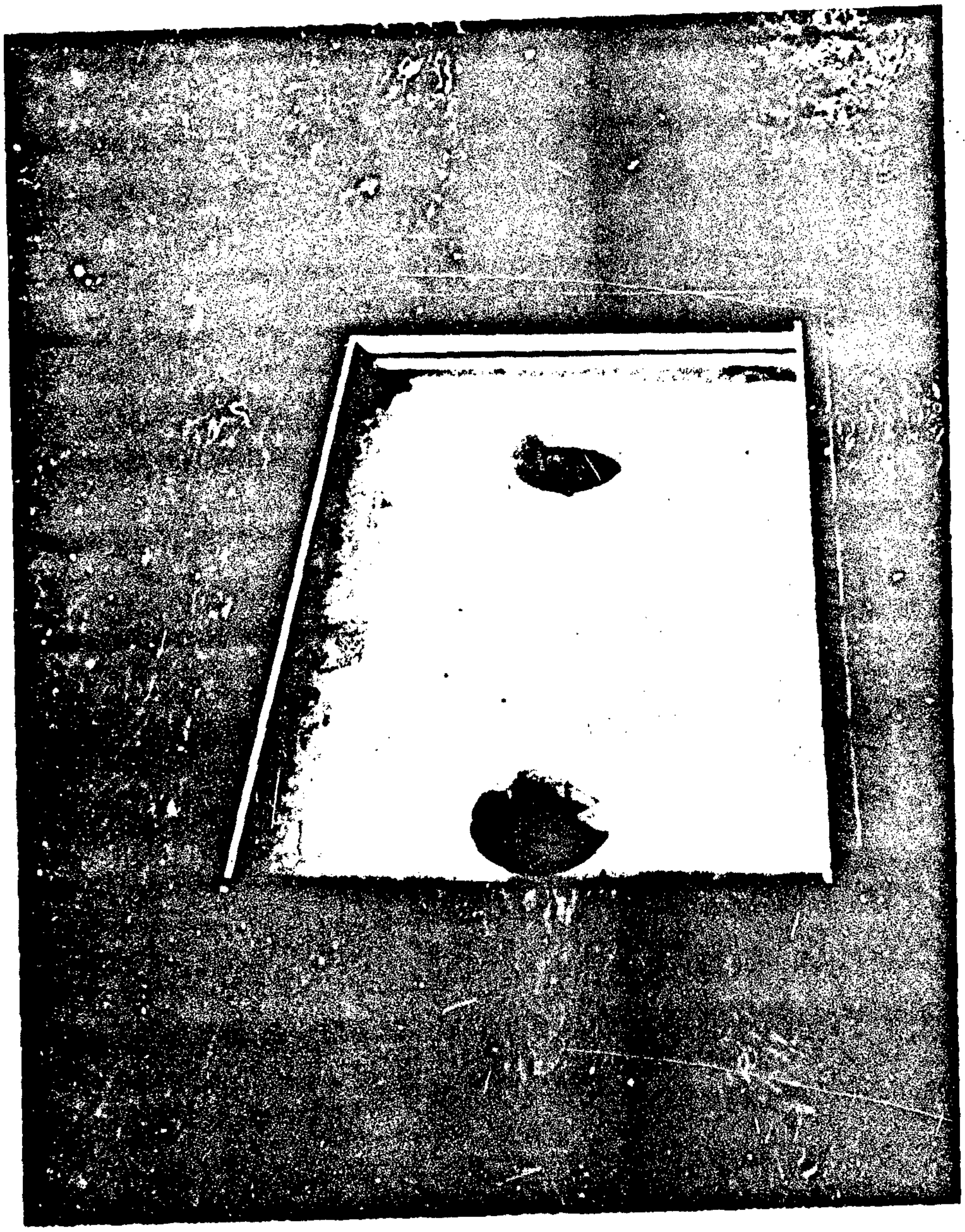


Fig 31 Holes cut in plywood and styrofoam backing in small window

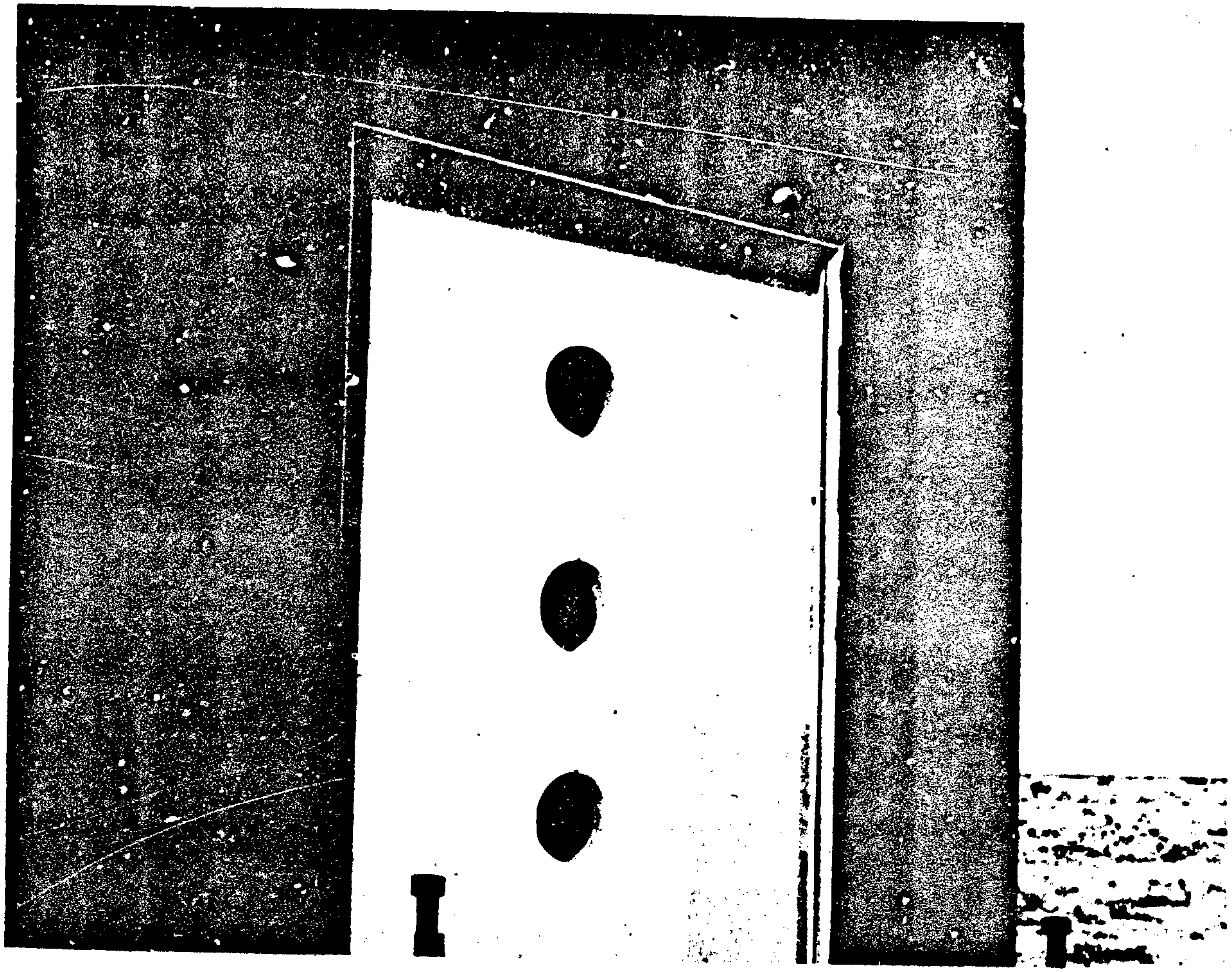


Fig 32  Holes cut in plywood and styrofoam backing in large window

Fig 33 Broken tempered glass

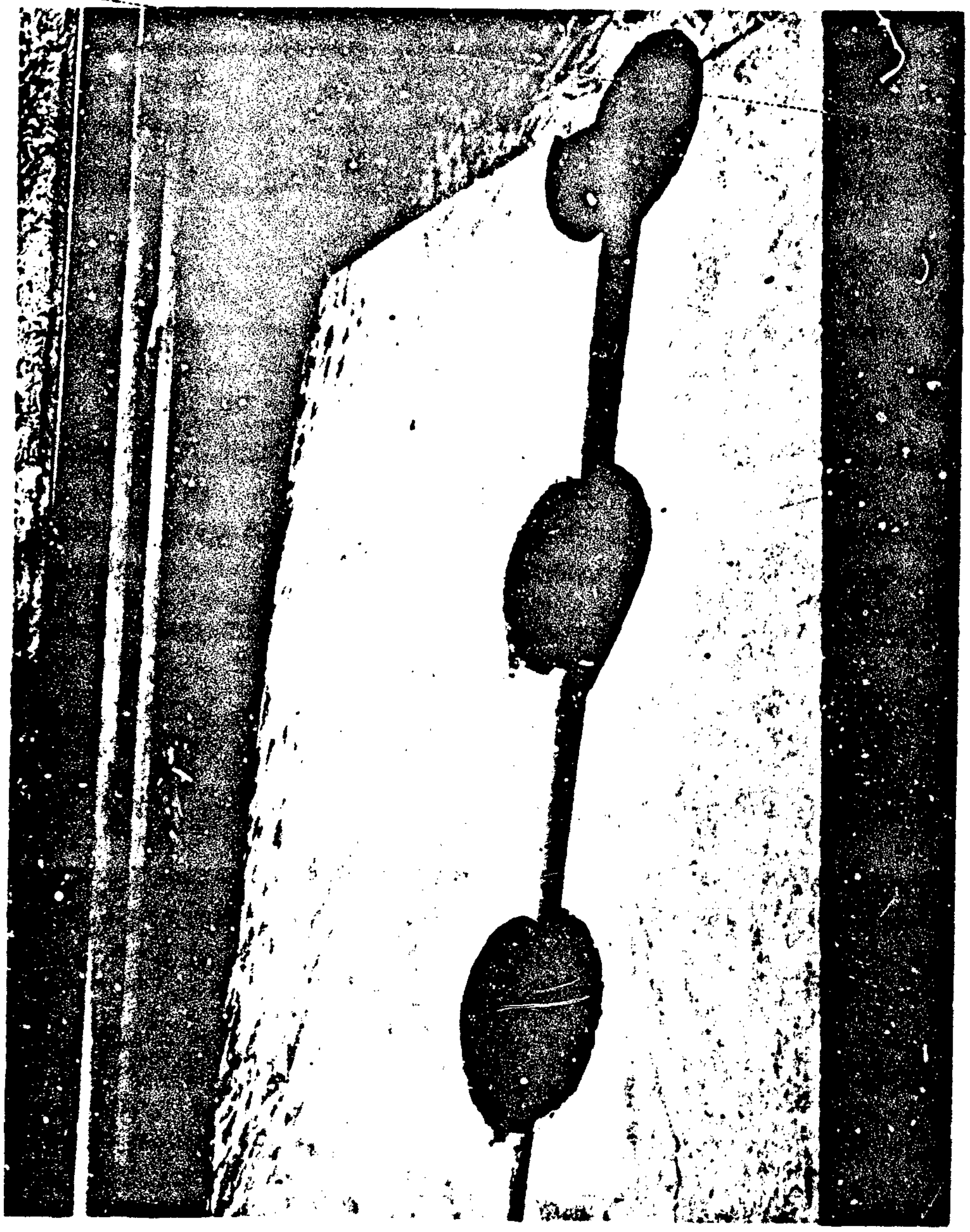


Fig 34 Damage to window backing

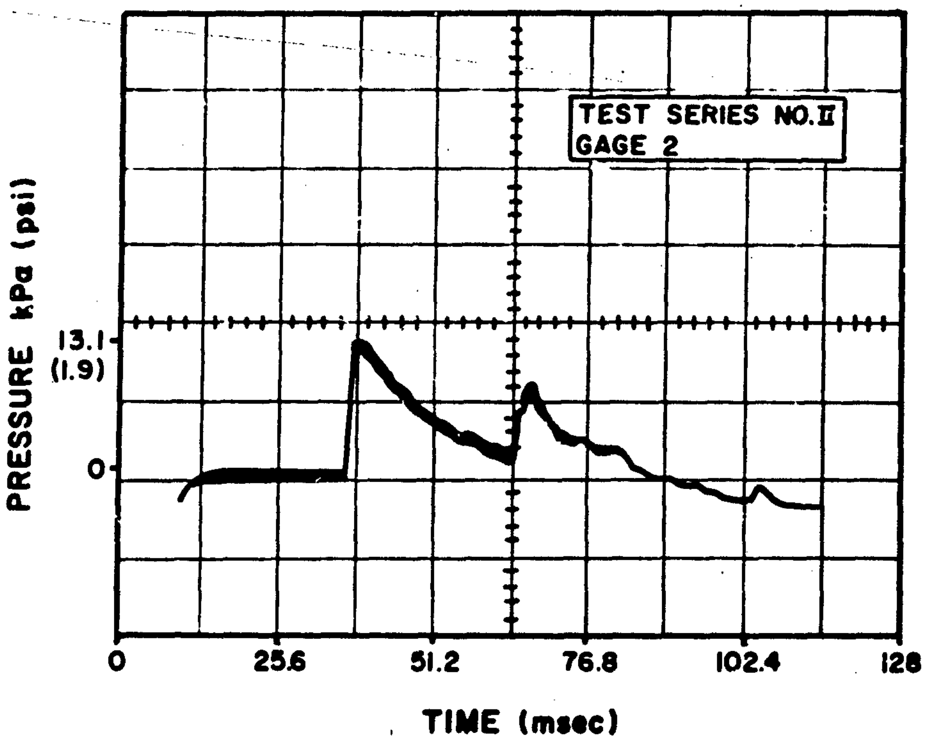



Fig 35 Typical recorded pressure-time curve

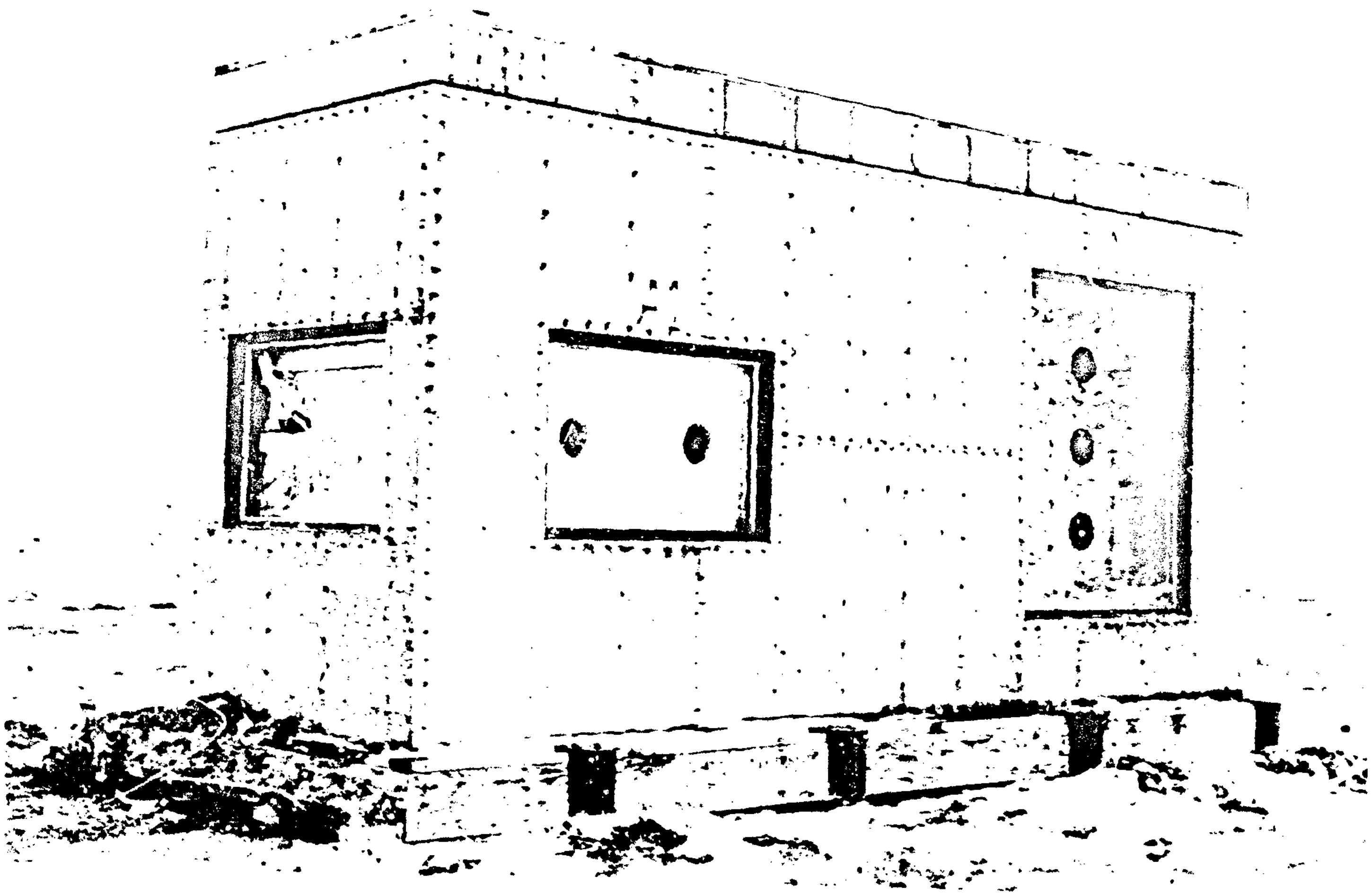


Fig 36  Broken regular glass in Structure A windows

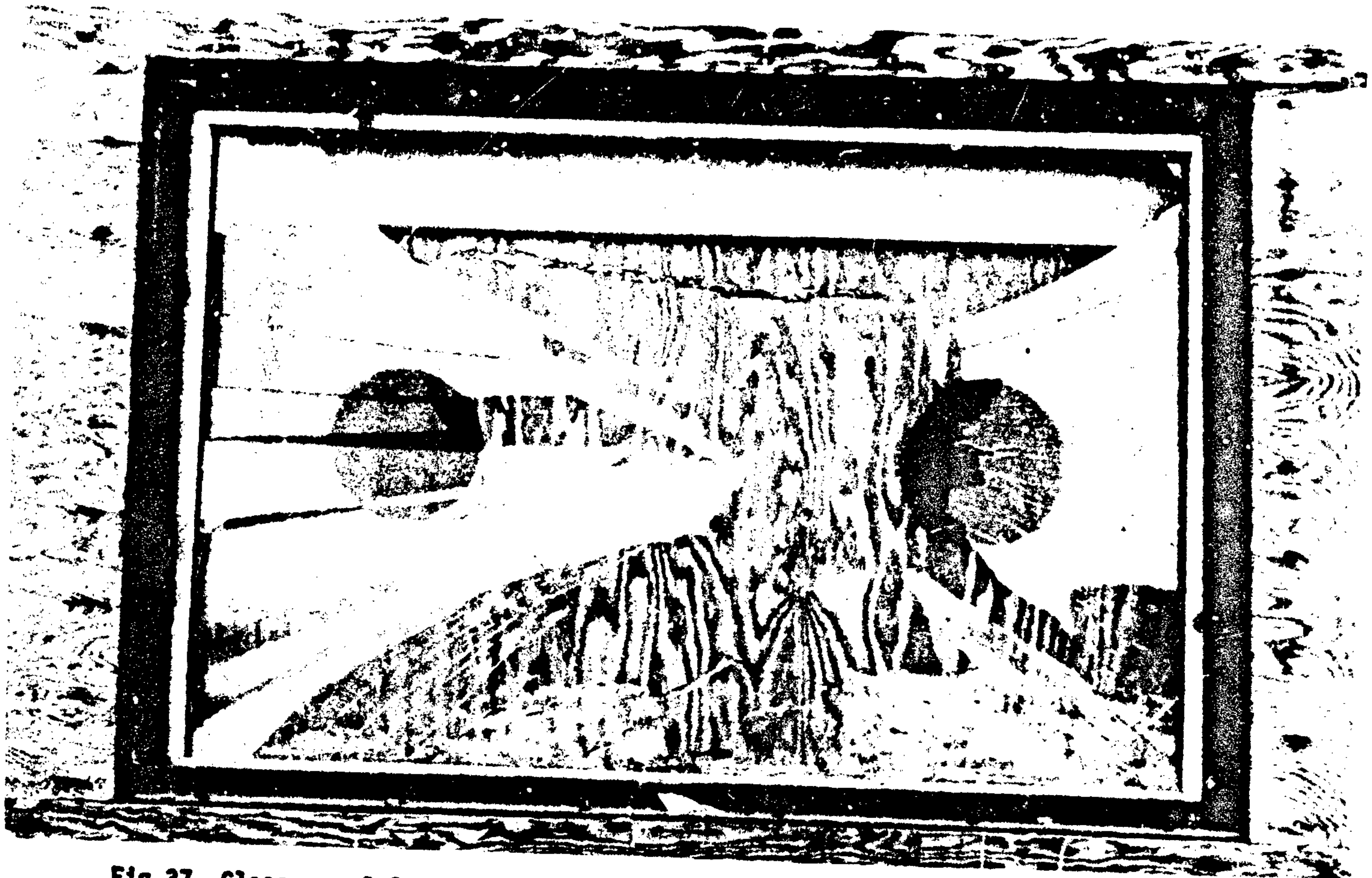


Fig 37  Close-up of front face window showing jagged nature of broken regular glass

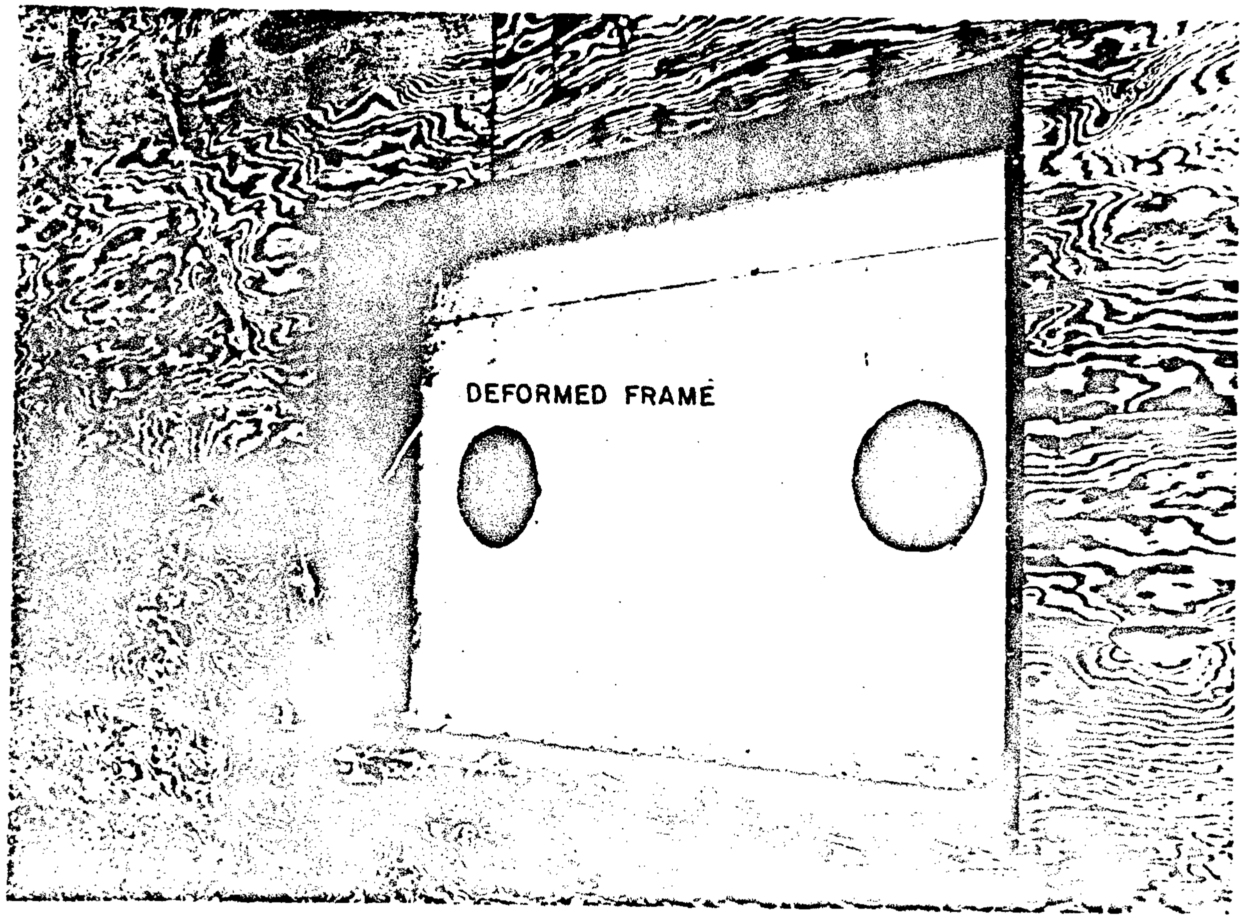



Fig 38 Broken tempered glass and deformed aluminum frame

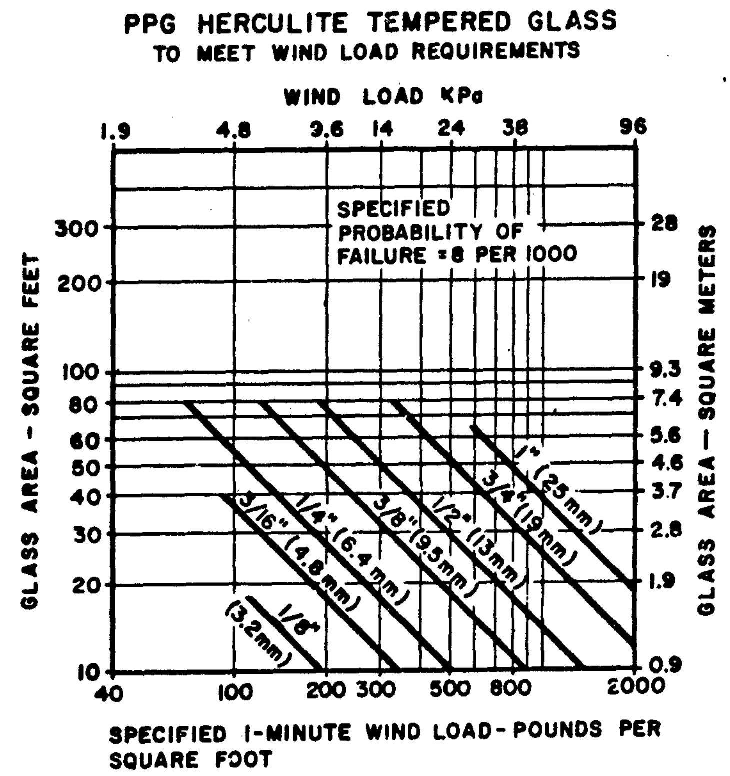



Fig 39 Wind load capacity of Herculite tempered glass (Ref 7)

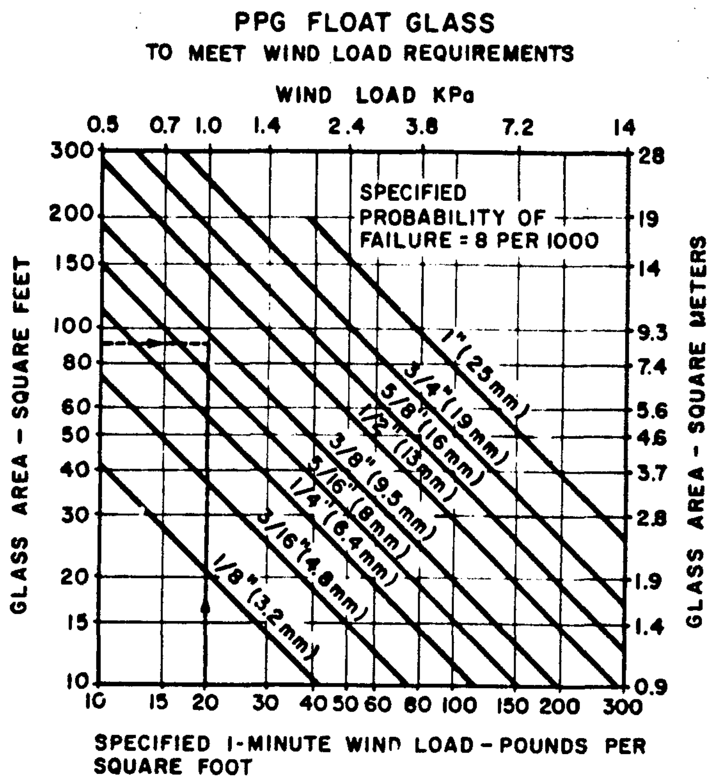



Fig 40 Wind load capacity of regular glass (Ref 7)

## APPENDIX

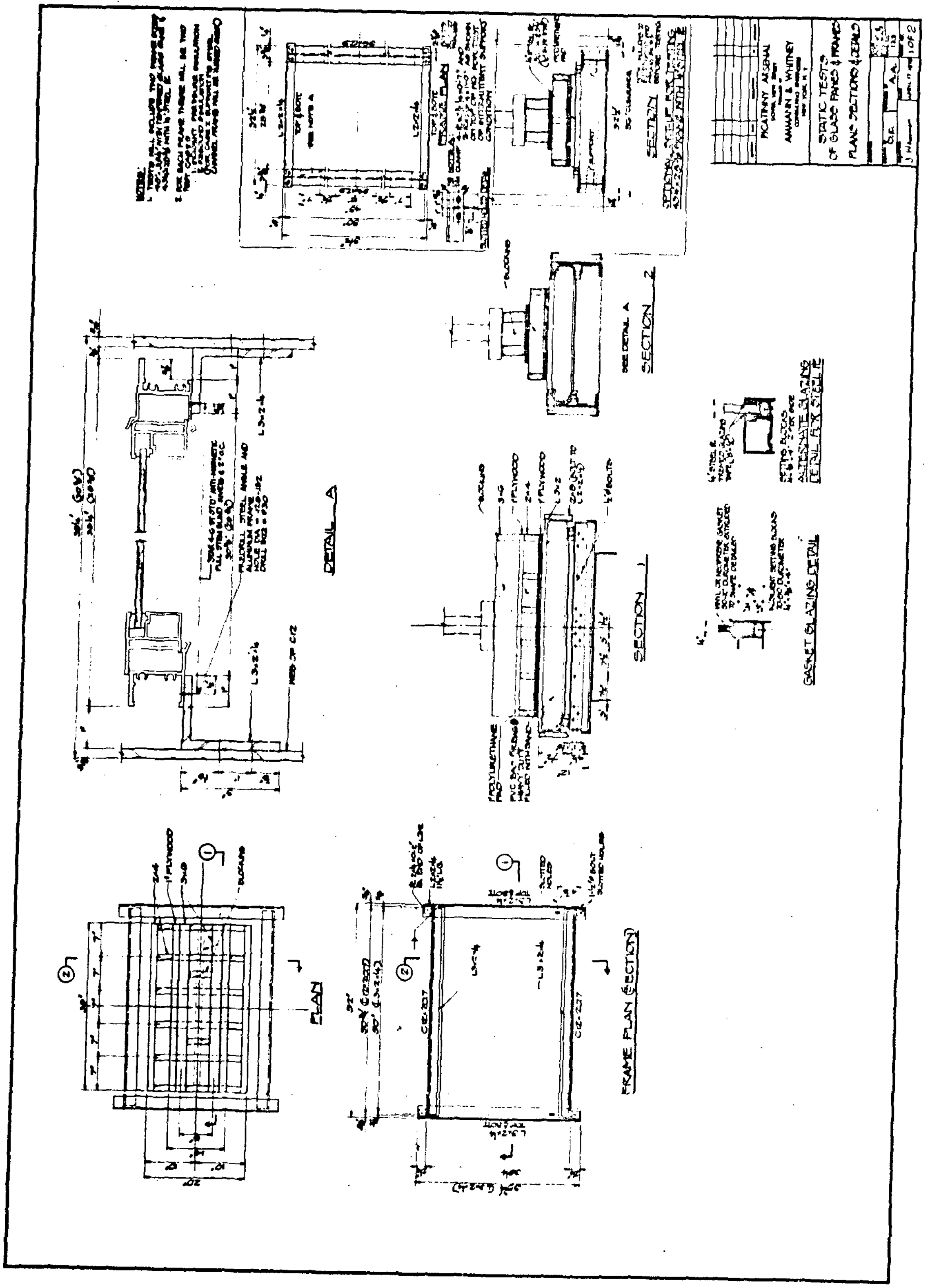
## ENGINEERING DRAWINGS

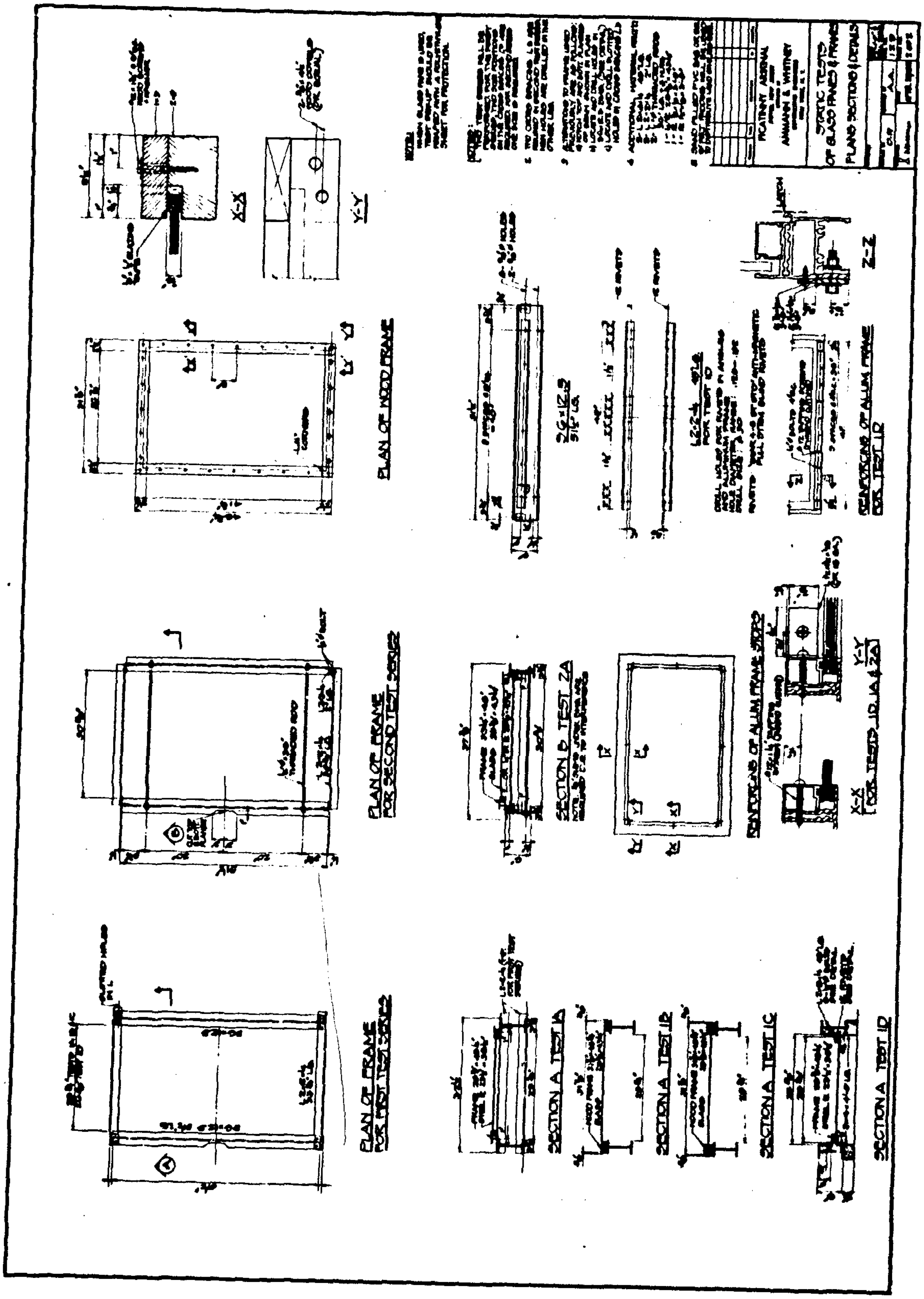
## APPENDIX

### ENGINEERING DRAWINGS

The following pages contain reduced-size copies of the engineering drawings prepared for the construction of the test structures and support framework for the static and dynamic tests. Drawing No. 129, Sheets Nos. 1 and 2 pertain to the static tests. Drawing No. 128, Sheets Nos. 1 through 5, and Drawing No. 130, Sheets Nos. 1 through 3 pertain to the dynamic tests.

The dynamic tests of the window glass and aluminum frames were performed in conjunction with tests of cold-formed steel panels, thus construction data related to the cold-formed steel panel tests are also included on Drawings Nos. 128 and 130.


PLAN
FRAME PLAN (SECTION)
DETAIL A
SECTION 1
SECTION 2
GASKET GLAZING DETAIL
PICATINNY ARSENAL
AMMANN & WHITNEY
STATIC TESTS OF GLASS PANES & FRAMES


PLAN OF FRAME FOR FIRST TEST SERIES
PLAN OF FRAME FOR SECOND TEST SERIES
PLAN OF WOOD FRAME
SECTION A TEST 1A
SECTION A TEST 1B
SECTION A TEST 1C
SECTION A TEST 1D
SECTION B TEST 2A
X-X
Y-Y
Z-Z

| TEST SHOT | | | WINDOW POSITIONS (TEST STRUCTURE A) | | | | | | STEEL DECK & ROOF | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | CHARGE WEIGHT | psi | 1 SW | 2 SW | 3 LW | 4 LW | 5 SW | REMARKS | PANEL SIZE | CONNECTION TYPE | CONNECTION SIZE | CONNECTION DETAIL | REMARKS |
| 1 | 2,000# | [illegible] | [illegible] | [illegible] | RLS | RLS | [illegible] | [illegible] | [illegible] 24 GA. | S | [illegible] | [illegible] | [illegible] |
| 2 | 2,000# | [illegible] | [illegible] | [illegible] | RLS | RLS | [illegible] | | [illegible] 24 GA. | S | [illegible] | [illegible] | POSSIBLE FAILURE |
| 3 | 2,000# | 1.0 | [illegible] | [illegible] | RLS | RLS | [illegible] | | [illegible] | W | [illegible] | [illegible] | REUSABLE |
| 4 | 2,000# | 1.0 | FDSS | – | – | – | – | | [illegible] | W | [illegible] | [illegible] | SAME DECK AS TEST 3 |
| 5 | 2,000# | 1.0 | – | – | – | – | – | | [illegible] | S | [illegible] | [illegible] | SCREW CONNECTION TEST ([illegible]) |
| 6 | 2,000# | | | | | | | PENDING RESULTS OF PREVIOUS TESTS | | | | | PENDING RESULTS OF PREVIOUS TESTS |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

## LEGEND

SW - SMALL WINDOW
LW - LARGE WINDOW
[illegible] - REGULAR [illegible] THICK SMALL WINDOW
[illegible] - REGULAR [illegible] THICK, SMALL WINDOW
RLS - REGULAR [illegible] THICK, LARGE WINDOW
RLS - REGULAR [illegible] THICK, LARGE WINDOW
FDSS - FRAMED [illegible] THICK SMALL WINDOW
[illegible] - [illegible] THICK, SMALL WINDOW
S - SELF TAPPING SCREWS
W - [illegible]
NS - [illegible] STUD

NOTES:
1 SEE SHEET [illegible] FOR STEEL DECK CONNECTION DETAILS
2 SEE SHEET [illegible] FOR FRAMED WINDOW DETAILS
3 SEE DWG. [illegible] SHEET [illegible] FOR DETAILS OF REGULAR GLASS [illegible] FRAMING.

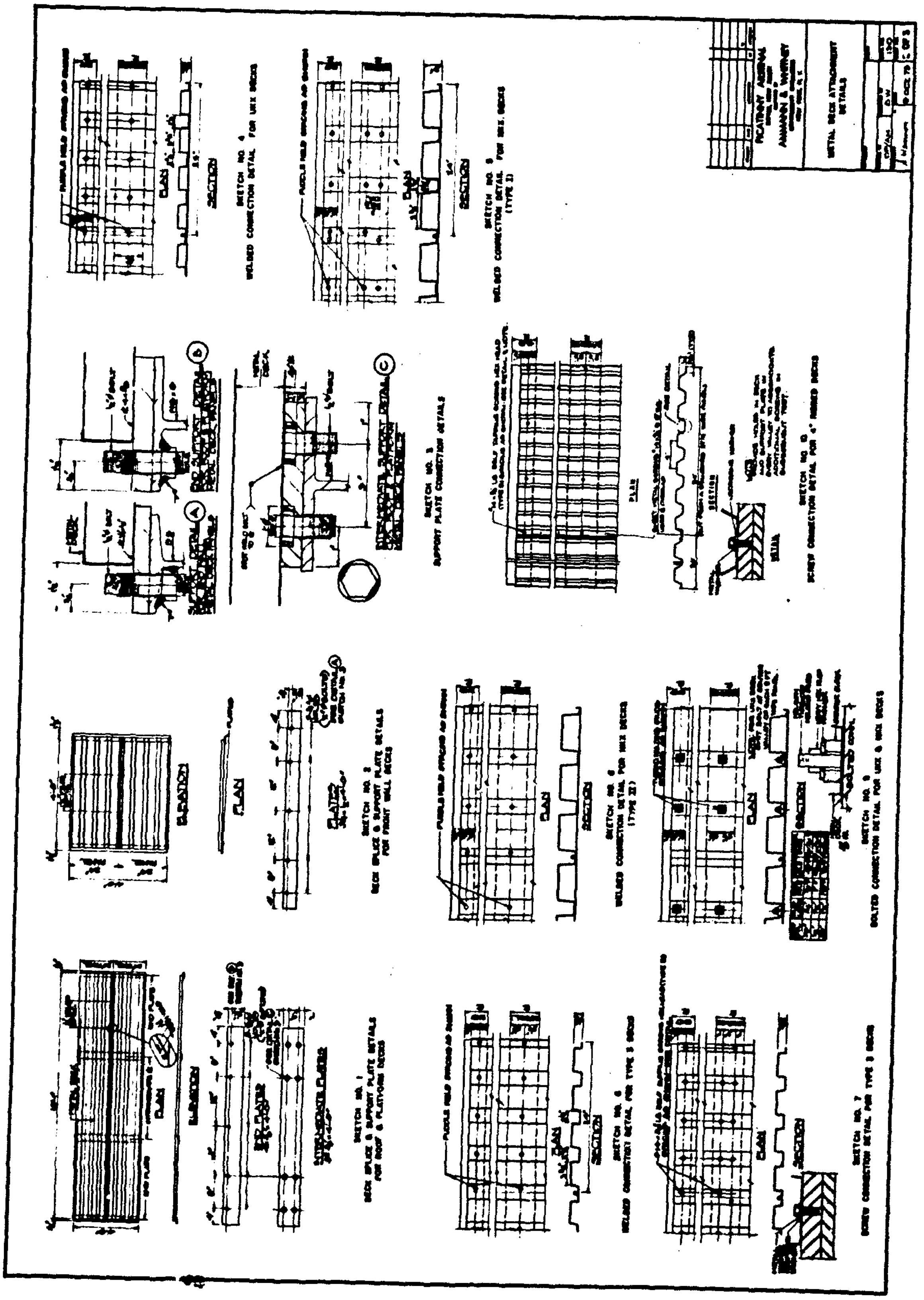
| TEST SHOT | | | WINDOW POSITIONS (TEST STRUCTURE B) | | | | | STEEL DECK & FRONT FACE | | | | | STEEL DECK & ROOF | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | CHARGE WEIGHT | psi | 1 SW | 2 SW | 3 LW | 4 LW | REMARKS | PANEL SIZE | CONNECTION TYPE | CONNECTION SIZE | CONNECTION DETAIL | REMARKS | PANEL SIZE | CONNECTION TYPE | CONNECTION SIZE | CONNECTION DETAIL | REMARKS |
| 1 | 2,000# | [illegible] | FDSS | – | – | – | | [illegible] | W | [illegible] | [illegible] | REUSABLE | [illegible] | W | [illegible] | [illegible] | REUSABLE |
| 2 | 2,000# | [illegible] | – | – | – | – | | [illegible] | W | [illegible] | [illegible] | SAME DECK AS TEST 1 | [illegible] | W | [illegible] | [illegible] | SAME DECK AS TEST 1 |
| 3 | 2,000# | [illegible] | [illegible] | – | – | – | | [illegible] | W | [illegible] | [illegible] | POSSIBLE FAILURE | [illegible] | W | [illegible] | [illegible] | NON-REUSABLE |
| 4 | 2,000# | [illegible] | – | – | – | – | | [illegible] | W | [illegible] | [illegible] | POSSIBLE FAILURE | [illegible] | S | [illegible] | [illegible] | SCREW CONNECTION TEST (SHEAR) |
| 5 | 2,000# | [illegible] | FDSS | – | – | – | | | | | | PENDING RESULTS OF PREVIOUS TESTS | [illegible] | W | [illegible] | [illegible] | WELDED CONNECTION TEST |
| 6 | 2,000# | | | | | | PENDING RESULTS OF PREVIOUS TESTS | | | | | PENDING RESULTS OF PREVIOUS TESTS | | | | | PENDING RESULTS OF PREVIOUS TESTS |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

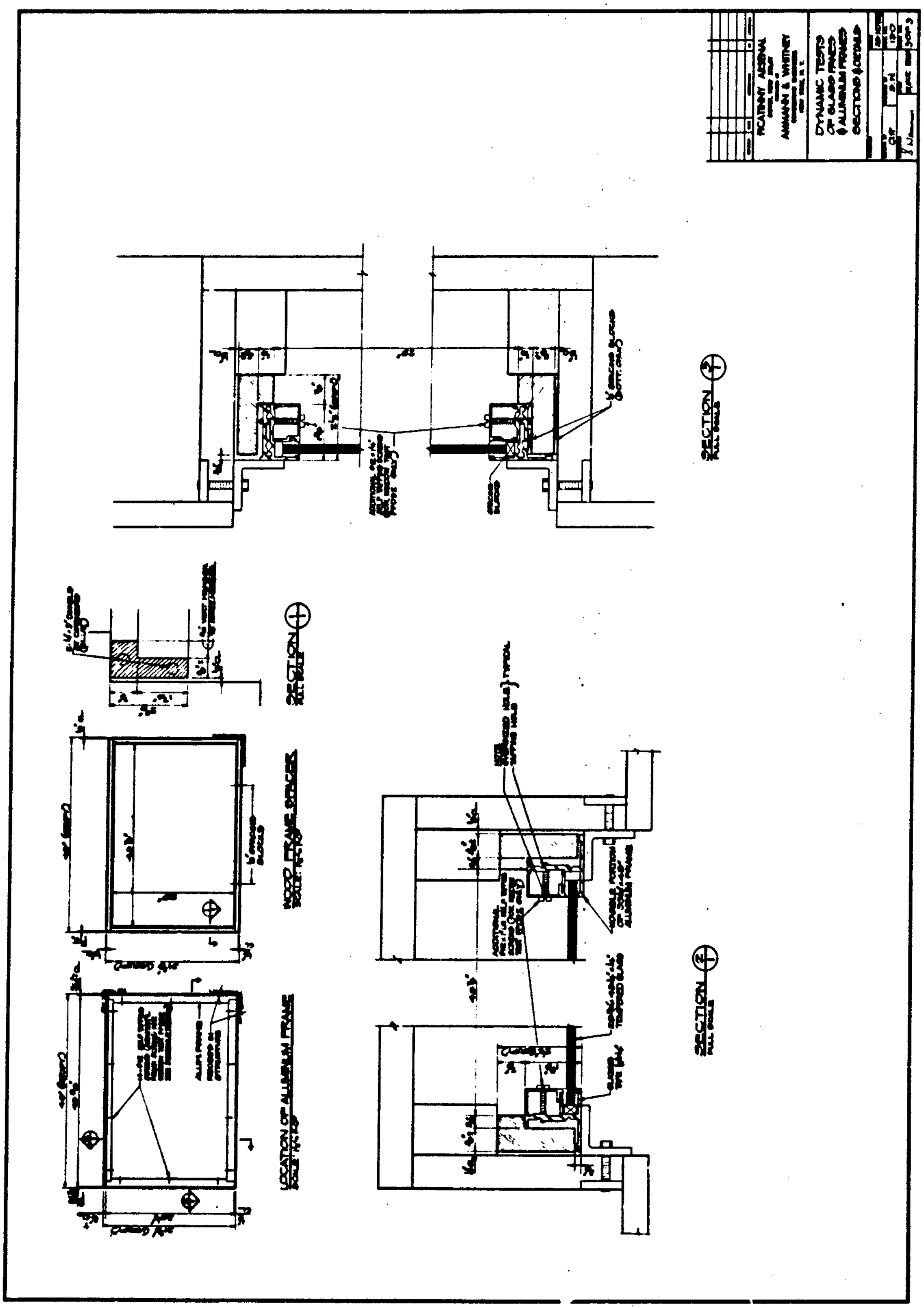
| TEST SHOT | | TEST STRUCTURE C (STEEL DECK) | | | | | | TEST STRUCTURE D (STEEL DECK) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | CHARGE WEIGHT | psi | PANEL SIZE | CONNECTION TYPE | CONNECTION SIZE | CONNECTION DETAIL | REMARKS | psi | PANEL SIZE | CONNECTION TYPE | CONNECTION SIZE | CONNECTION DETAIL | REMARKS |
| 1 | 2,000# | [illegible] | [illegible] | W | [illegible] | [illegible] | POSSIBLE FAILURE | [illegible] | [illegible] | W | 1" | [illegible] | REUSABLE |
| 2 | 2,000# | [illegible] | [illegible] | NS | [illegible] | [illegible] | REUSABLE BOLTED CONNECTION TEST | [illegible] | [illegible] | W | 1" | [illegible] | SAME DECK AS TEST 1 |
| 3 | 2,000# | [illegible] | [illegible] | NS | [illegible] | [illegible] | SAME DECK AS TEST 2 | [illegible] | [illegible] | W | [illegible] | [illegible] | NON-REUSABLE |
| 4 | 2,000# | 7.0 | [illegible] | NS | [illegible] | [illegible] | NON-REUSABLE | [illegible] | [illegible] | NS | [illegible] | [illegible] | REUSABLE BOLTED CONNECTION TEST |
| 5 | 2,000# | 7.0 | [illegible] | W | 1" | [illegible] | POSSIBLE FAILURE | 7.0 | [illegible] | NS | [illegible] | [illegible] | NON-REUSABLE |
| 6 | 2,000# | | | | | | PENDING RESULTS OF PREVIOUS TESTS | | | | | | PENDING RESULTS OF PREVIOUS TESTS |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

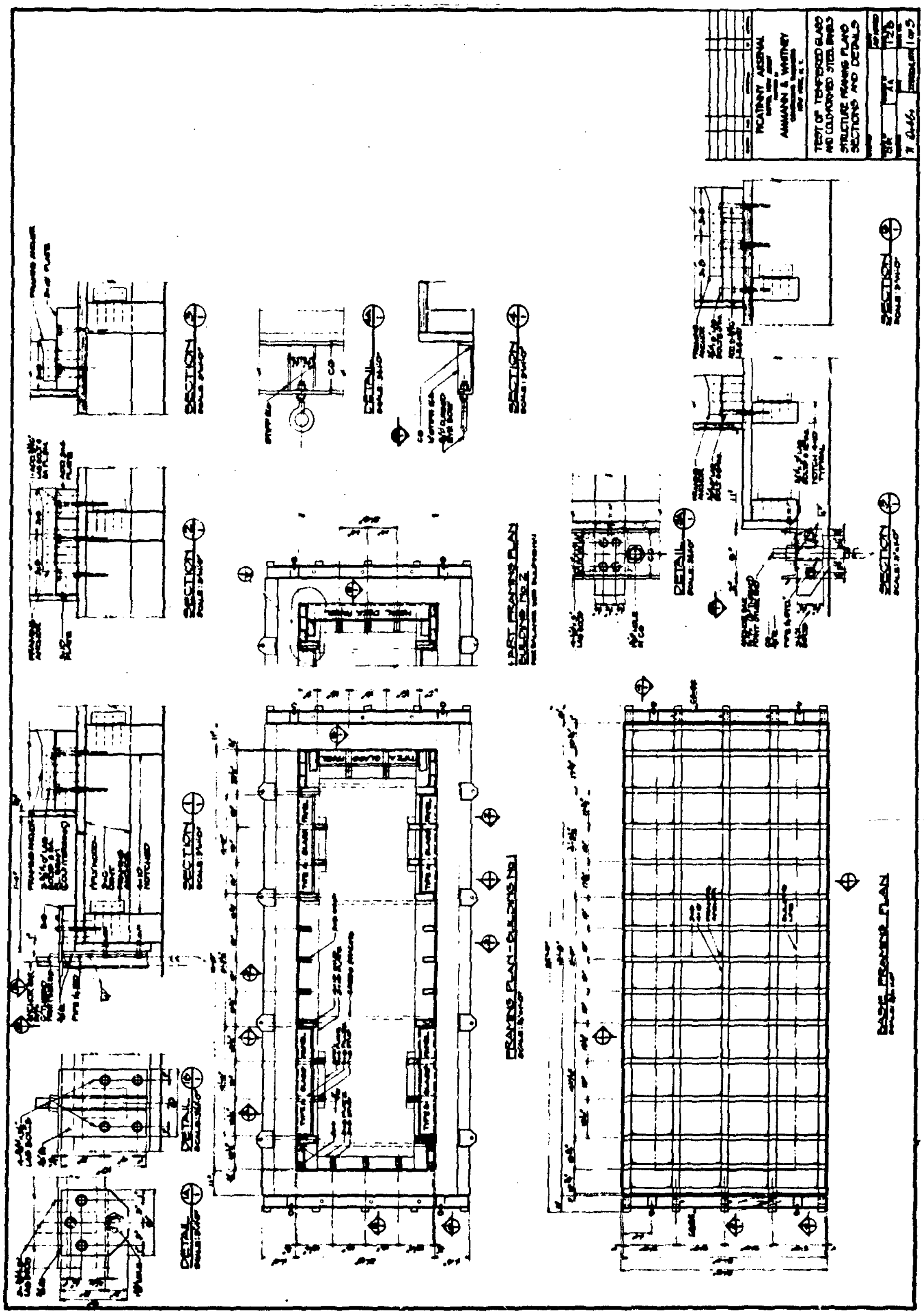
PICATINNY ARSENAL
[illegible], NEW JERSEY
[illegible]
AMMANN & WHITNEY
CONSULTING ENGINEERS
NEW YORK, N.Y.

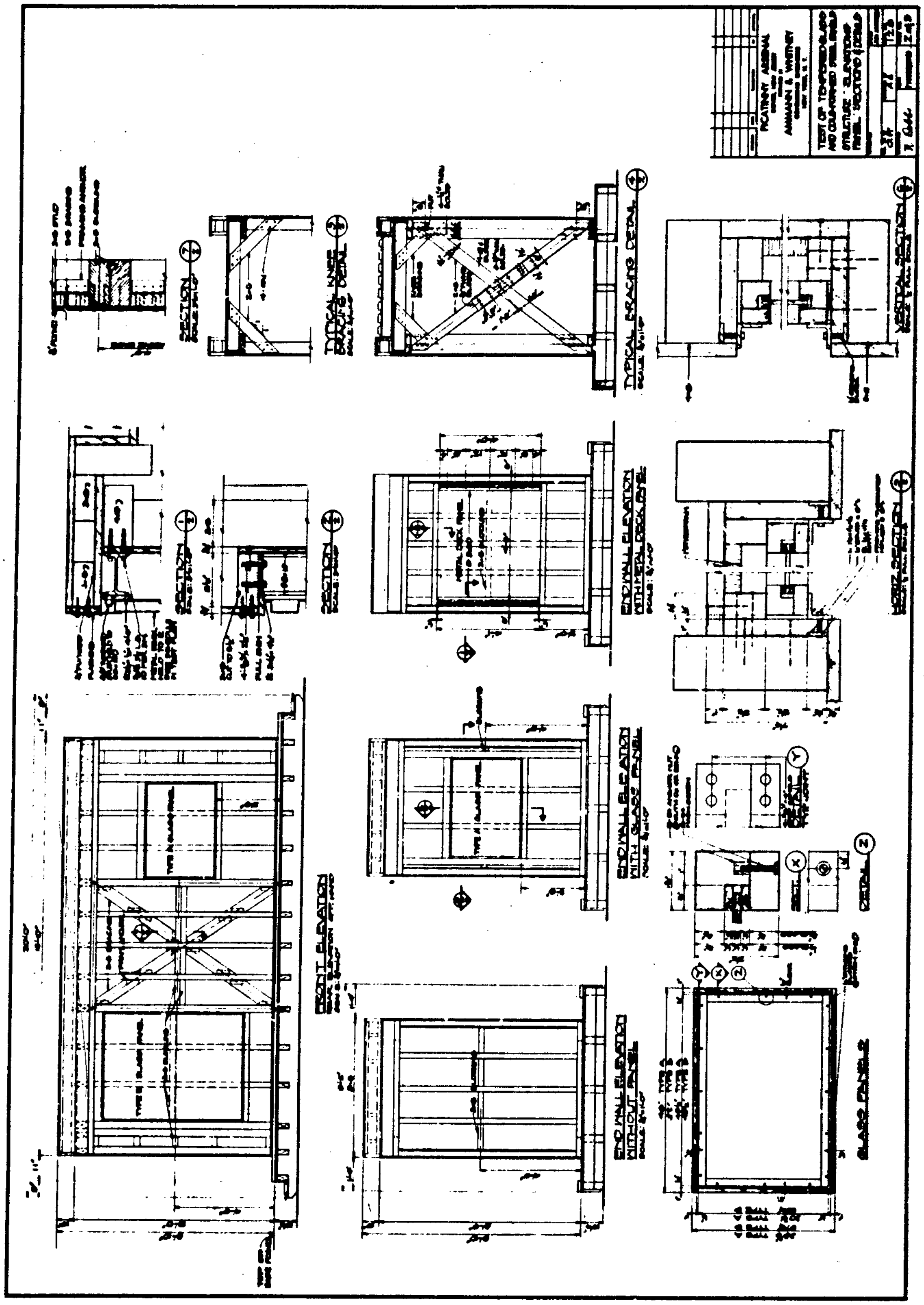
TEST PLAN
METAL DECK AND WINDOWS

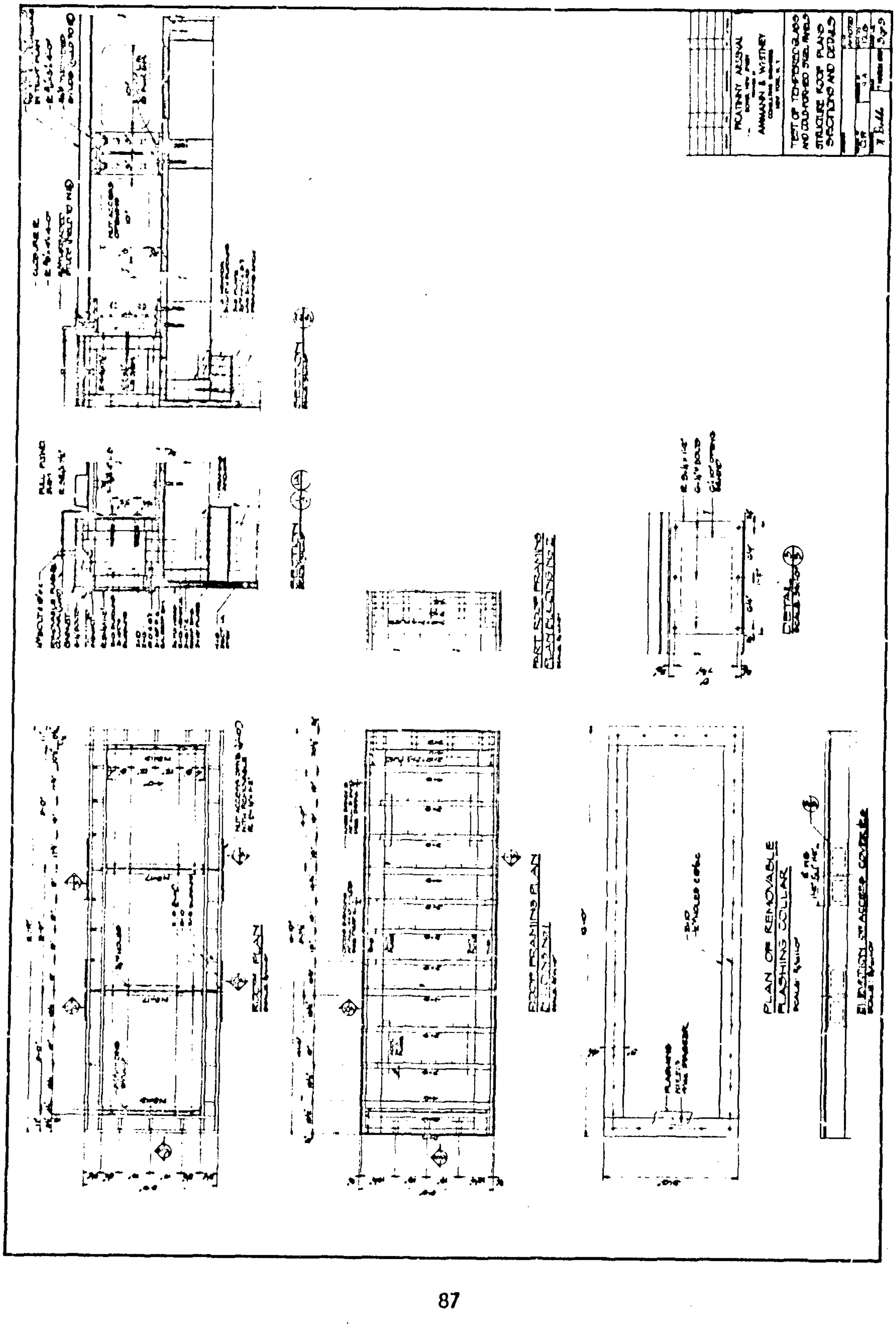
| | | |
|---|---|---|
| [illegible] AM | [illegible] SW | [illegible] |
| [illegible] | 9 OCT. 73 | 1 OF 3 |

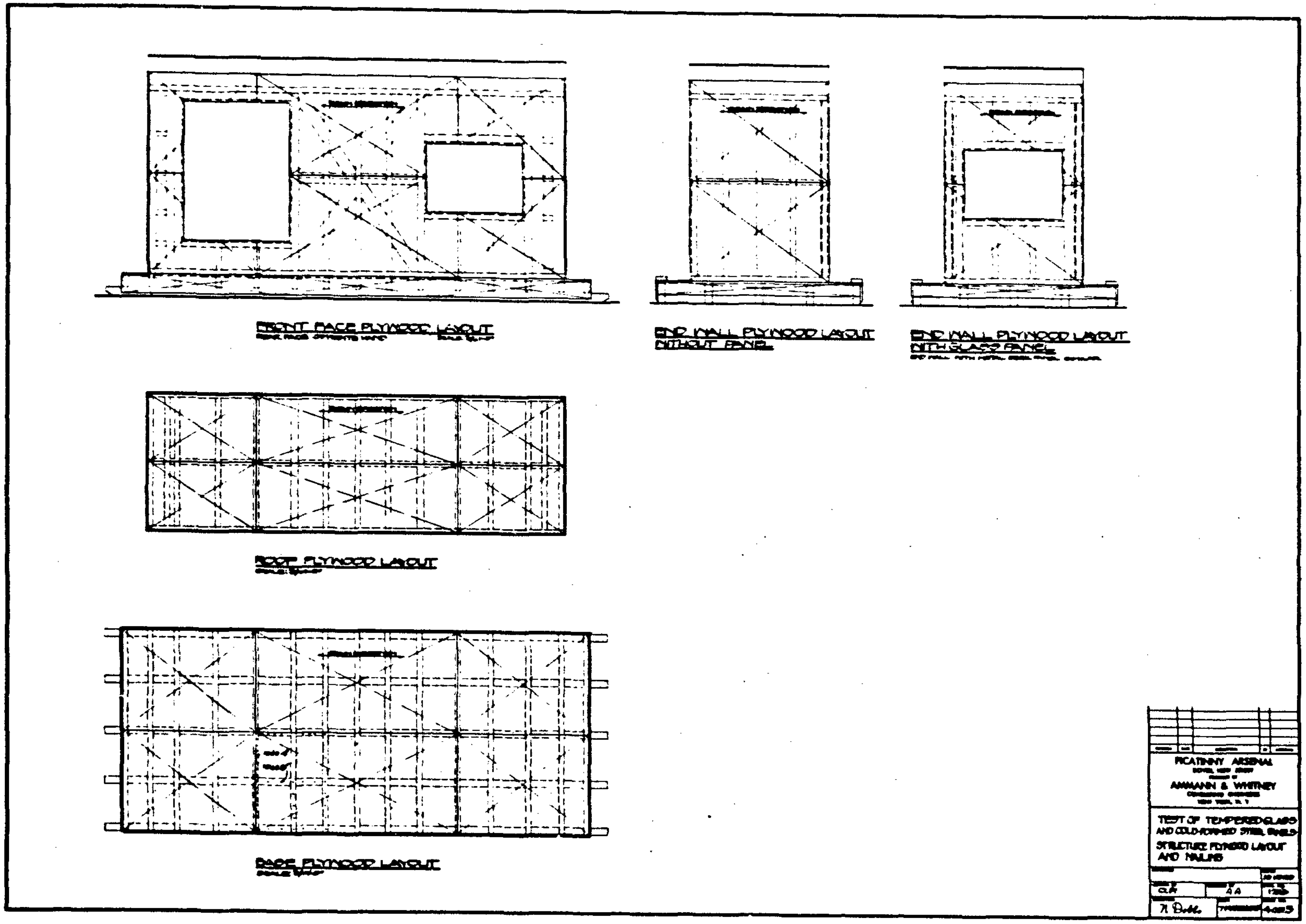

SKETCH NO. 1
DECK SPLICE & SUPPORT PLATE DETAILS FOR ROOF & PLATFORM DECKS
SKETCH NO. 2
DECK SPLICE & SUPPORT PLATE DETAILS FOR FRONT WALL DECKS
SKETCH NO. 3
SUPPORT PLATE CONNECTION DETAILS
SKETCH NO. 4
WELDED CONNECTION DETAIL FOR UKX DECKS
SKETCH NO. 5
WELDED CONNECTION DETAIL FOR NKX DECKS
(TYPE I)
SKETCH NO. 6
WELDED CONNECTION DETAIL FOR TYPE 3 DECKS
SKETCH NO. 6
WELDED CONNECTION DETAIL FOR NKX DECKS
(TYPE II)
SKETCH NO. 7
SCREW CONNECTION DETAIL FOR TYPE 3 DECKS
SKETCH NO. 8
BOLTED CONNECTION DETAIL FOR UKX & NKX DECKS
SKETCH NO. 10
SCREW CONNECTION DETAIL FOR 4" RIBBED DECKS
PICATINNY ARSENAL
AMMANN & WHITNEY
METAL DECK ATTACHMENT DETAILS

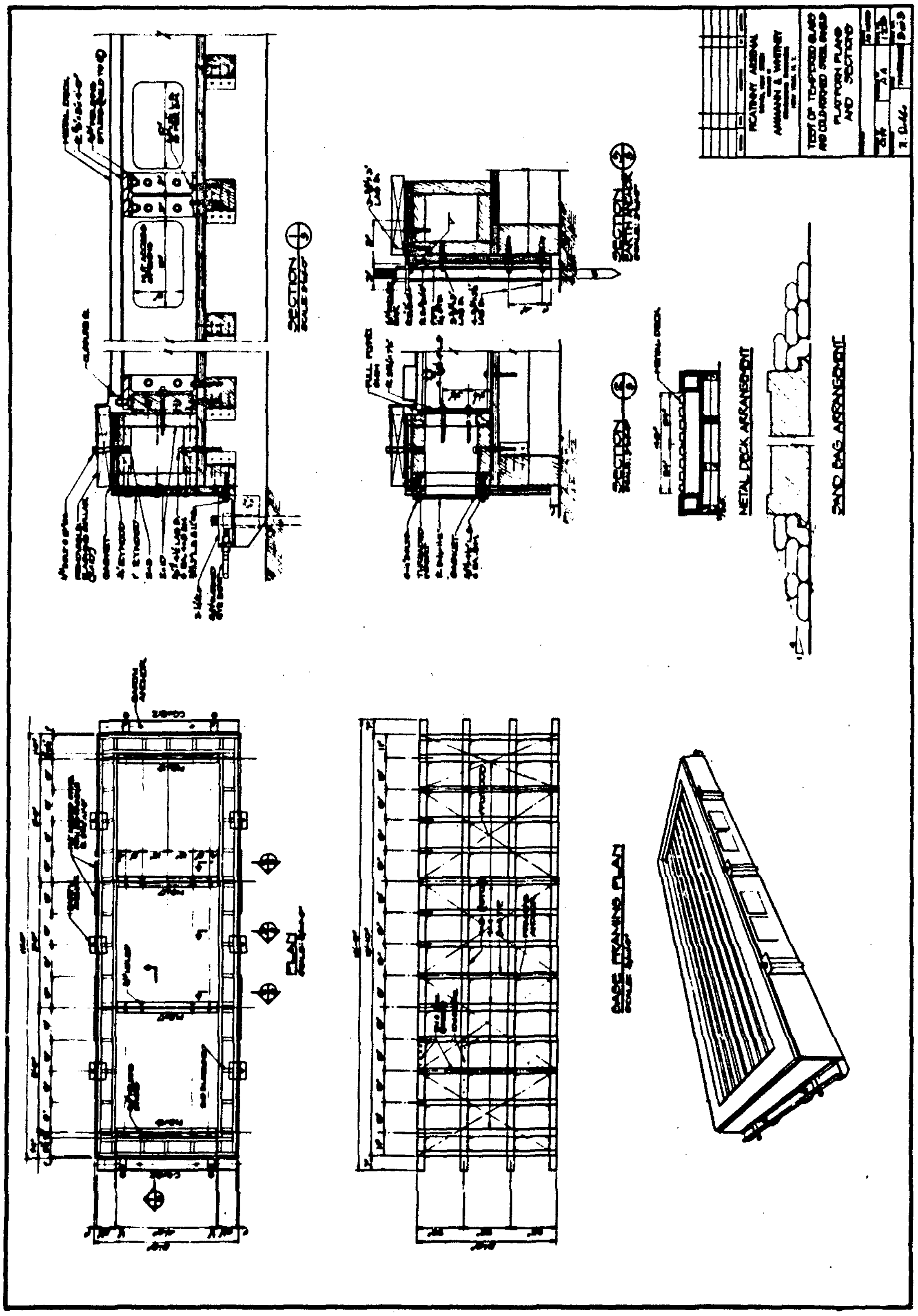

PICATINNY ARSENAL
AMMANN & WHITNEY
DYNAMIC TESTS
OF GLASS PANES
& ALUMINUM FRAMES
SECTIONS & DETAILS
LOCATION OF ALUMINUM FRAME
WOOD FRAME SPACER
SECTION
SECTION
SECTION


PICATINNY ARSENAL
AMMANN & WHITNEY
TEST OF TEMPERED GLASS AND COLDFORMED STEEL PANELS
STRUCTURE FRAMING PLANS SECTIONS AND DETAILS
FRAMING PLAN - BUILDING No 1
BASE FRAMING PLAN
SECTION
DETAIL




PICATINNY ARSENAL
AMMANN & WHITNEY
ROOF PLAN
ROOF FRAMING PLAN
PLAN OF REMOVABLE FLASHING COLLAR


FRONT FACE PLYWOOD LAYOUT
END WALL PLYWOOD LAYOUT
WITHOUT PANEL
END WALL PLYWOOD LAYOUT
WITH GLASS PANEL
ROOF PLYWOOD LAYOUT
BASE PLYWOOD LAYOUT
PICATINNY ARSENAL
AMMANN & WHITNEY
TEST OF TEMPERED GLASS
AND COLD-FORMED STEEL PANELS
STRUCTURE PLYWOOD LAYOUT
AND NAILING



SECTION
PLAN
BASE FRAMING PLAN
METAL DECK ARRANGEMENT
SAND BAG ARRANGEMENT
PICATINNY ARSENAL
AMMANN & WHITNEY
PLATFORM PLANS AND SECTIONS

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